Mu2e Status and Progress

Doug Glenzinski
Fermilab
For the Mu2e Collaboration

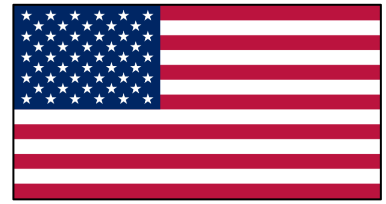
User's Executive Committee
April 25, 2014

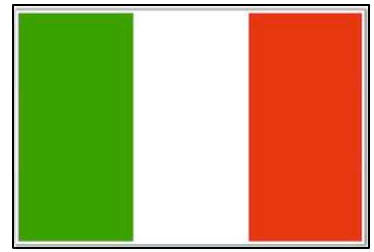
U.S. DEPARTMENT OF ENERGY | Office of Science

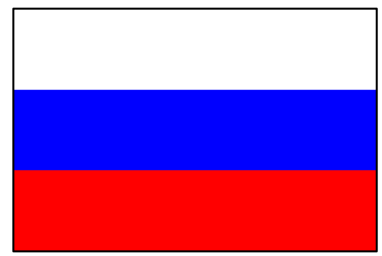
Fermilab

Mu2e Collaboration


Mu2e Collaboration 2013







- ~130 Collaborators, 26 Institutions, 3 Countries
  +2 Institutions and +20 members over last year

Outline

- Physics Motivation
- Mu2e Concept
- Scope and Schedule
- Recent Progress
- Challenges
- Conclusions

Mu2e Physics Motivation

- Mu2e will measure Charged Lepton Flavor Violation (CLFV) with a single-event sensitivity of 2×10^{-17}

$$\mu^- N \rightarrow e^- N$$

- This experiment
  - Offers compelling discovery sensitivity over broad array of Beyond the Standard Model (BSM) parameter space
  - Provides unique and incisive probe of BSM physics
  - Has the world's best sensitivity to CLFV

Some CLFV Processes

Process	Current Limit	Next Generation exp
$\tau \to \mu\eta$	BR < 6.5 E-8	10^{-9} - 10^{-10} (Belle II)
$\tau \to \mu\gamma$	BR < 6.8 E-8	
$\tau \to \mu\mu\mu$	BR < 3.2 E-8	
$\tau \to eee$	BR < 3.6 E-8	
$K_L \to e\mu$	BR < 4.7 E-12	NA62
$K^+ \to \pi^+ e^- \mu^+$	BR < 1.3 E-11	
$B^0 \to e\mu$	BR < 7.8 E-8	Belle II, LHCb
$B^+ \to K^+ e\mu$	BR < 9.1 E-8	
$\mu^+ \to e^+\gamma$	BR < 5.7 E-13	10^{-14} (MEG)
$\mu^+ \to e^+e^+e^-$	BR < 1.0 E-12	10^{-16} (PSI)
$\mu N \to eN$	$R_{\mu e}$ < 7.0 E-13	10^{-17} (Mu2e, COMET)

- The most sensitive CLFV probes use muons

CLFV Predictions

M.Blanke, A.J.Buras, B.Duling, S.Recksiegel, C.Tarantino

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^-\to e^-e^+e^-)}{Br(\mu\to e\gamma)}$	$0.02\ldots1$	$\sim 6\cdot10^{-3}$	$\sim 6\cdot10^{-3}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.4$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to\mu^-\mu^+\mu^-)}{Br(\tau\to\mu\gamma)}$	$0.04\ldots0.4$	$\sim 2\cdot10^{-3}$	$0.06\ldots0.1$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.3$	$\sim 2\cdot10^{-3}$	$0.02\ldots0.04$
$\frac{Br(\tau^-\to\mu^-e^+e^-)}{Br(\tau\to\mu\gamma)}$	$0.04\ldots0.3$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)}$	$0.8\ldots2.0$	~ 5	$0.3\ldots0.5$
$\frac{Br(\tau^-\to\mu^-\mu^+\mu^-)}{Br(\tau^-\to\mu^-e^+e^-)}$	$0.7\ldots1.6$	~ 0.2	$5\ldots10$
$\frac{R(\mu\mathrm{Ti}\to e\mathrm{Ti})}{Br(\mu\to e\gamma)}$	$10^{-3}\ldots10^{2}$	$\sim 5\cdot10^{-3}$	$0.08\ldots0.15$

arXiv:0909.5454v2[hep-ph]

Table 3: *Comparison of various ratios of branching ratios in the LHT model ($f = 1\,\mathrm{TeV}$) and in the MSSM without [92, 93] and with [96, 97] significant Higgs contributions.*

- Relative rates are model dependent
- Measure ratios to pin-down theory details

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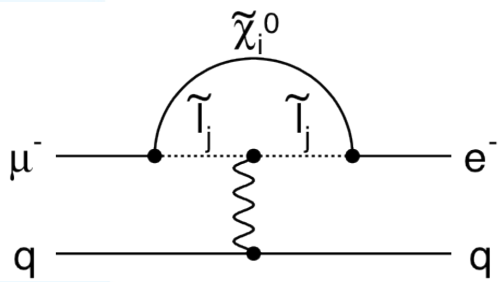
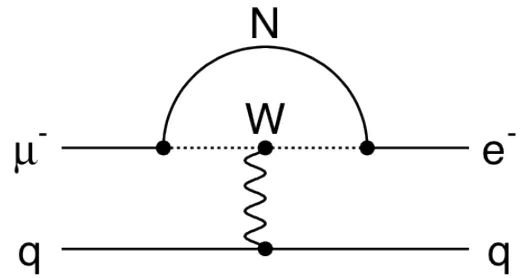
Mu2e Physics Reach

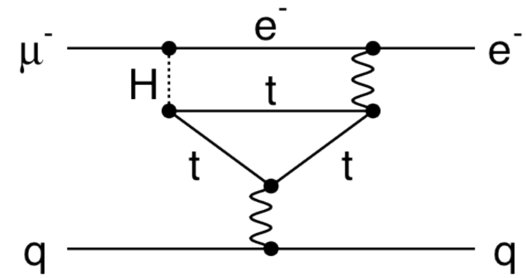
Loops



Supersymmetry

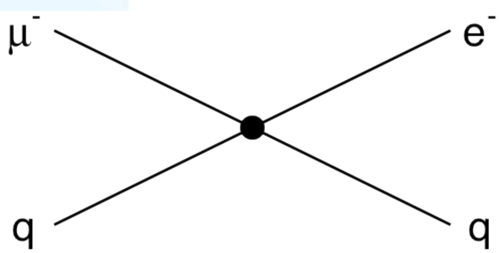


Heavy Neutrinos

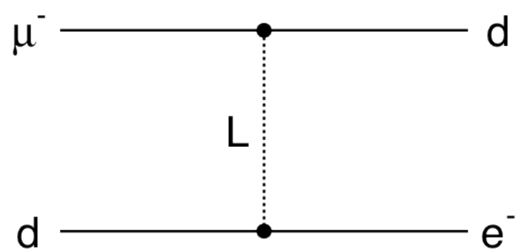


Two Higgs Doublets

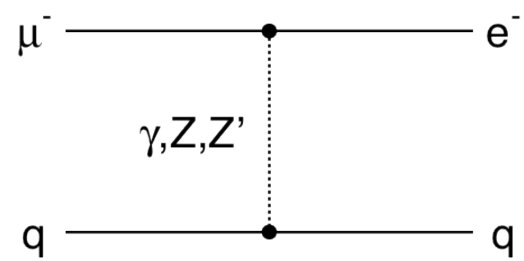
Contact Terms



Compositeness



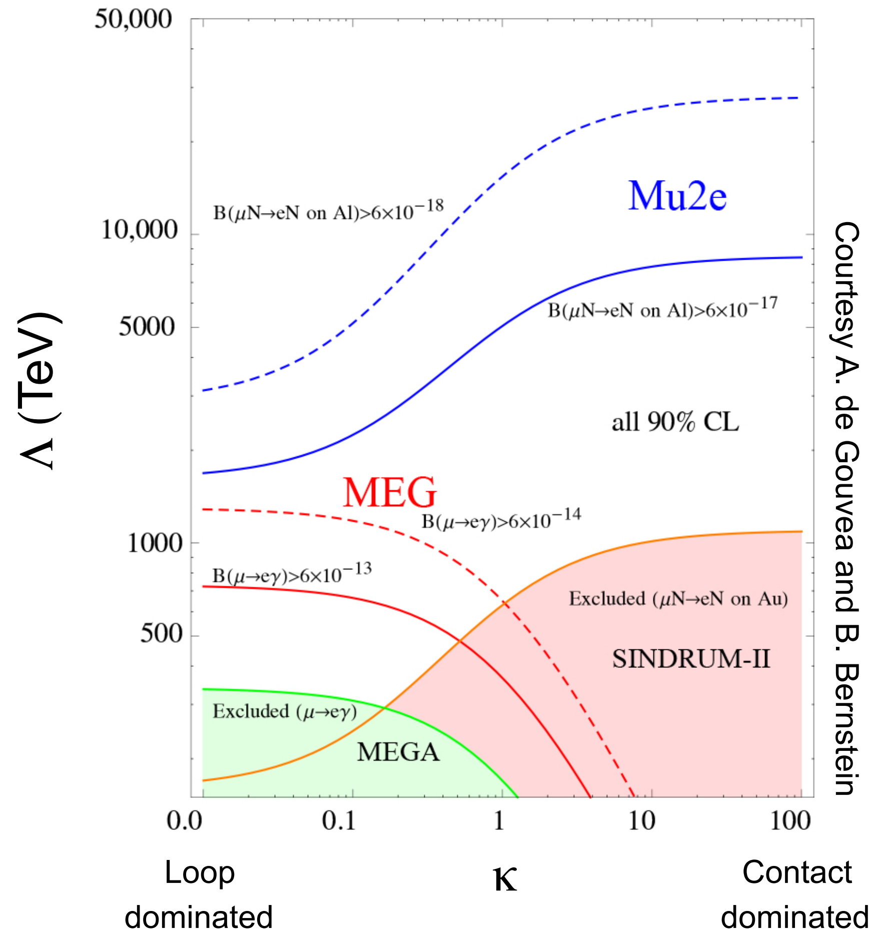
Leptoquarks



New Heavy Bosons / Anomalous Couplings

- Enables **discovery** sensitivity over broad swath of BSM parameter space

Mu2e Physics Reach



- Can probe mass scales >> LHC
  - Will eclipse MEG

Mu2e Physics Reach

W. Altmannshofer, A.J.Buras, S.Gori, P.Paradisi, D.M.Straub

★★★ Discovery Sensitivity

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0-\bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\mathrm{CP}}(B\to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B\to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B\to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B\to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s\to\mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+\to\pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L\to\pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu\to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau\to\mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu+N\to e+N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

arXiv:0909.1333[hep-ph]

Table 8: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

Mu2e Physics Reach

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★★★ Discovery Sensitivity

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\rm CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

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arXiv:0909.1333[hep-ph]

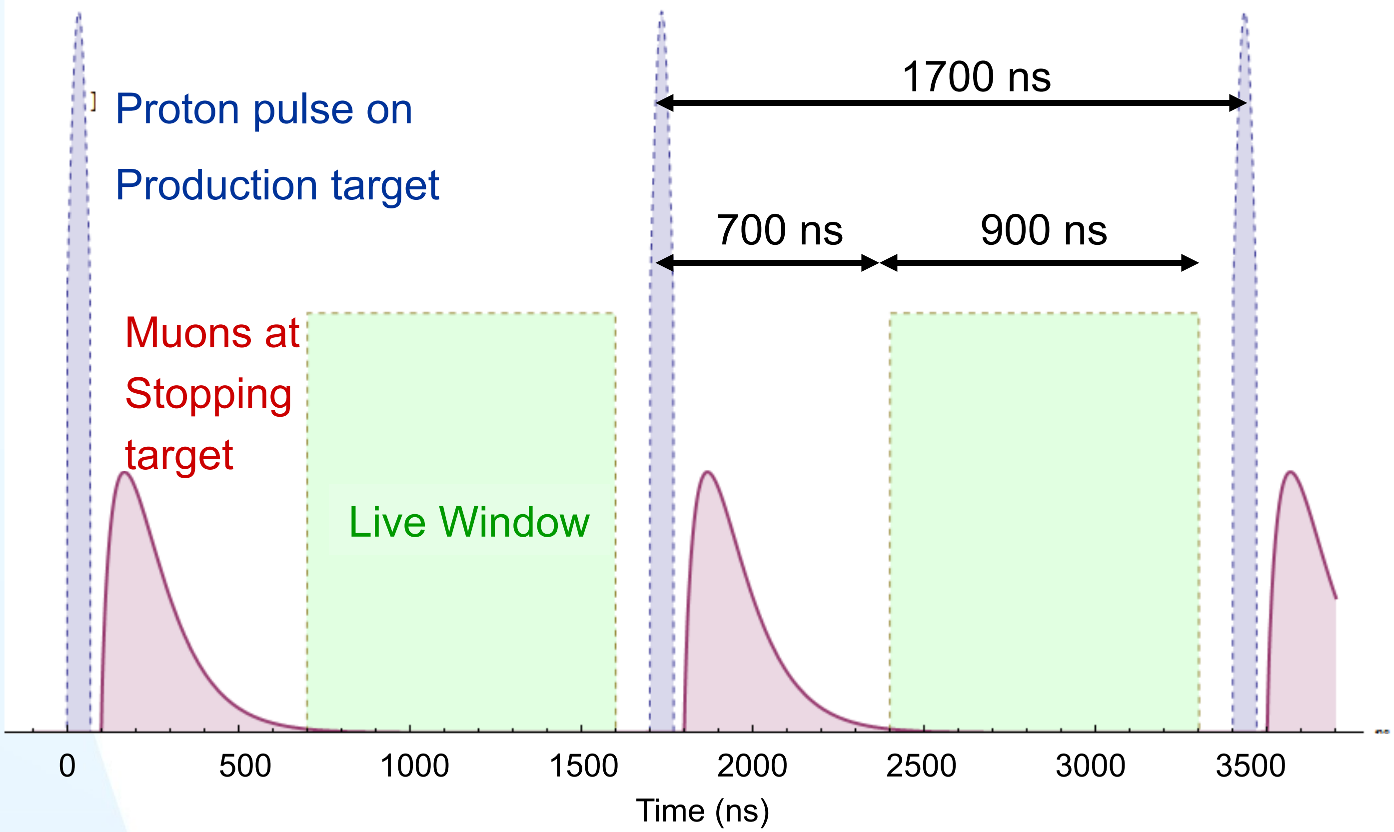
- Mu2e has discovery sensitivity across the board

How does Mu2e work?

Mu2e Concept

- Generate a beam of low momentum muons
  - Use 8 GeV protons from existing Fermilab complex
- Stop the muons in orbit around a nucleus
  - We plan to use aluminum stopping target
  - In orbit around aluminum τ_{μ}^{Al} = 864 ns
  - Important in discriminating background
- Look for events consistent with the signal

Mu2e Concept



- Mu2e will use a pulsed proton beam and a delayed live gate to suppress prompt background

Mu2e Concept

- Generate a beam of low momentum muons
  - Use 8 GeV protons from existing Fermilab complex

- Stop the muons in orbit around a nucleus
  - We plan to use aluminum stopping target
  - In orbit around aluminum τ_{μ}^{Al} = 864 ns
  - Important in discriminating background

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Mu2e Signal

- The process is coherent
  - The nucleus is left intact
- Experimental signature is an electron and nothing else
  - Energy of electron : $E_e = m_\mu - E_{recoil} - E_{1S\text{-}B.E.}$
  - For aluminum: E_e=104.96 MeV
  - Important for discriminating background

Mu2e Background

Category	Source	Events
Intrinsic	μ Decay in Orbit	0.22
	Radiative μ Capture	<0.01
Late Arriving	Radiative π Capture	0.03
	Beam electrons	<0.01
	μ Decay in Flight	0.01
	π Decay in Flight	<0.01
Miscellaneous	Anti-proton induced	0.10
	Cosmic Ray induced	0.05
	Pat. Recognition Errors	<0.01
Total Background		0.41

(assuming 6E17 stopped muons in 6E7 s of beam time)

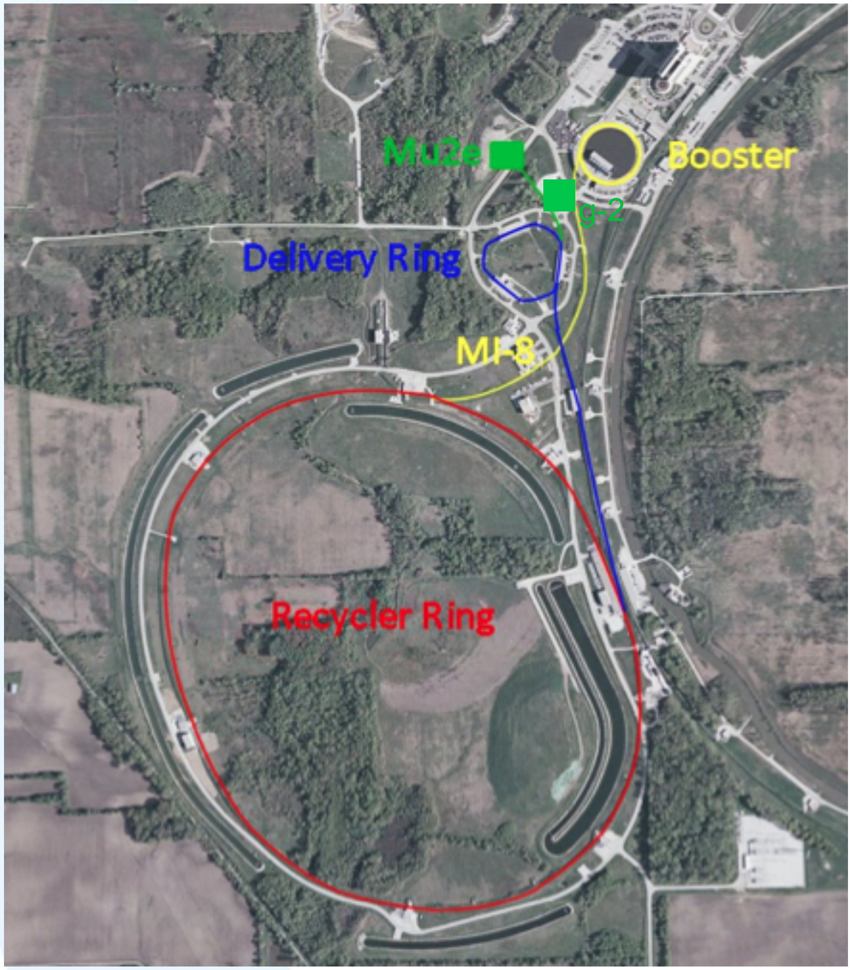
- Discovery sensitivity accomplished by suppressing backgrounds to <1 event total

Mu2e Scope and Schedule

Mu2e Scope

- Beam line capable of delivering 8kW of 8 GeV protons with the necessary time structure
- Experimental apparatus capable of
  - capturing low momentum muons
  - Delivering muons to the stopping target
  - Measuring high energy electrons originating from the stopping target
- An experimental hall to house the experiment

Mu2e Proton Beam

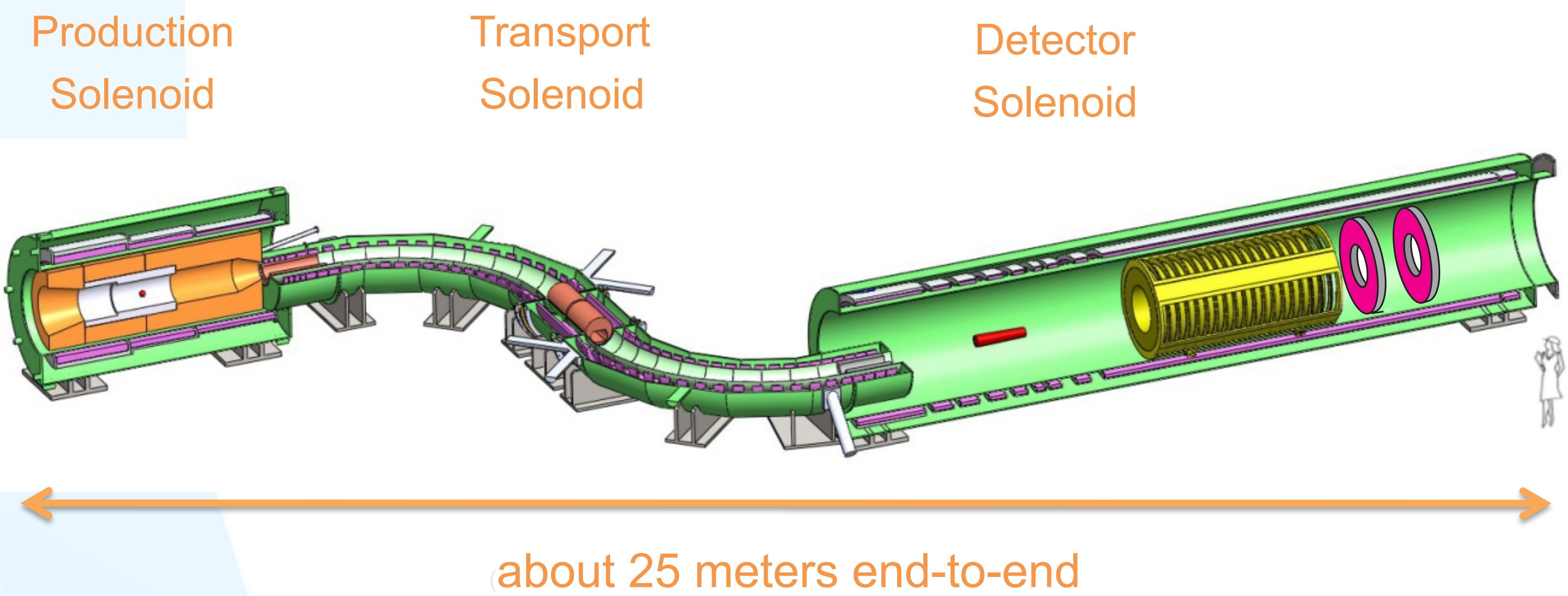


- Mu2e uses 8 GeV protons from Booster
- Mu2e and (g-2) will repurpose much of the Tevatron anti-proton complex to instead deliver muons.
- Mu2e can (and will) run simultaneously with NOvA.

Mitigating Out-Of-Time Protons

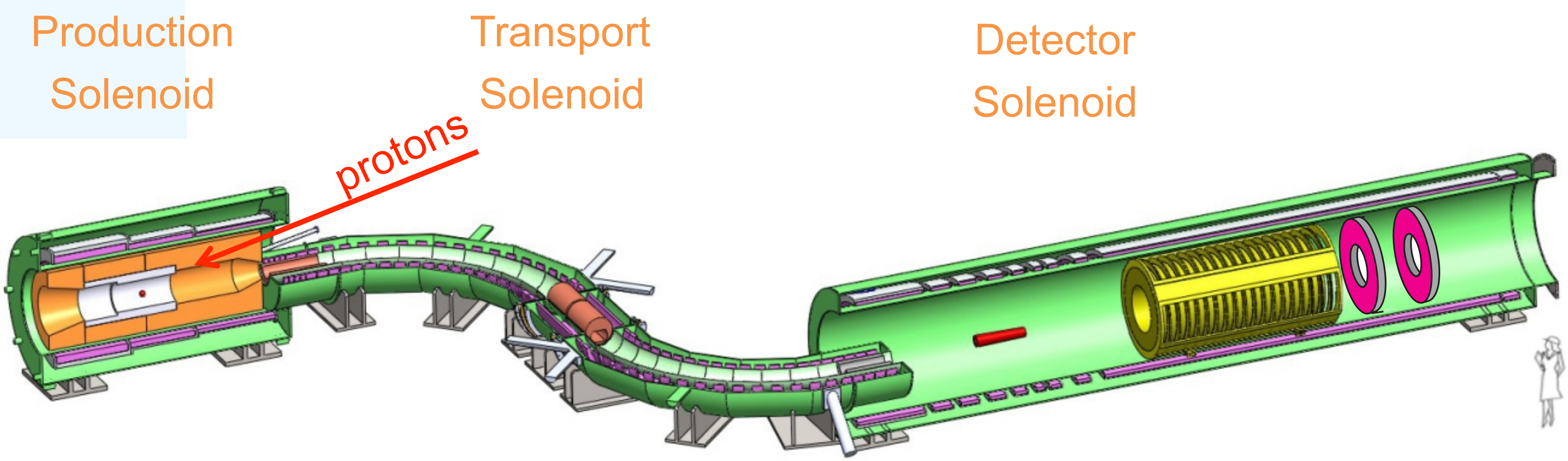
- The RF structure of the Recycler provides some "internal" extinction:
  - Extinction (Intrinsic) = few 10^{-5}
- A custom-made AC dipole placed just upstream of the production target provides additional "external" extinction:
  - Extinction (AC dipole) = $10^{-6} – 10^{-7}$
- Together they provide a total extinction:
  - Extinction (Total) = few $10^{-11} – 10^{-12}$

Mu2e Experimental Apparatus



- Consists of 3 solenoid systems

Mu2e Experimental Apparatus

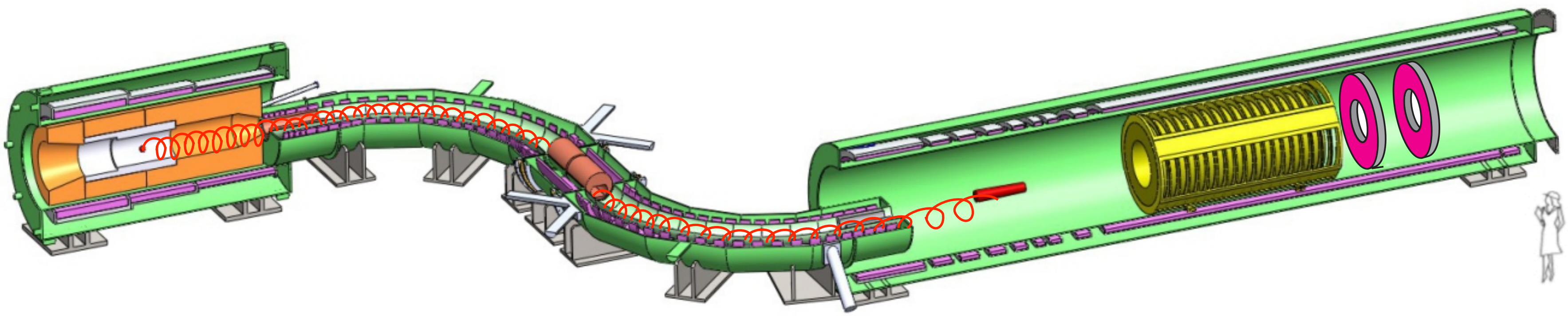


Production Solenoid:

8 GeV protons interact with a tungsten target to produce μ- (from π- decay)

- Consists of 3 solenoid systems

Mu2e Experimental Apparatus

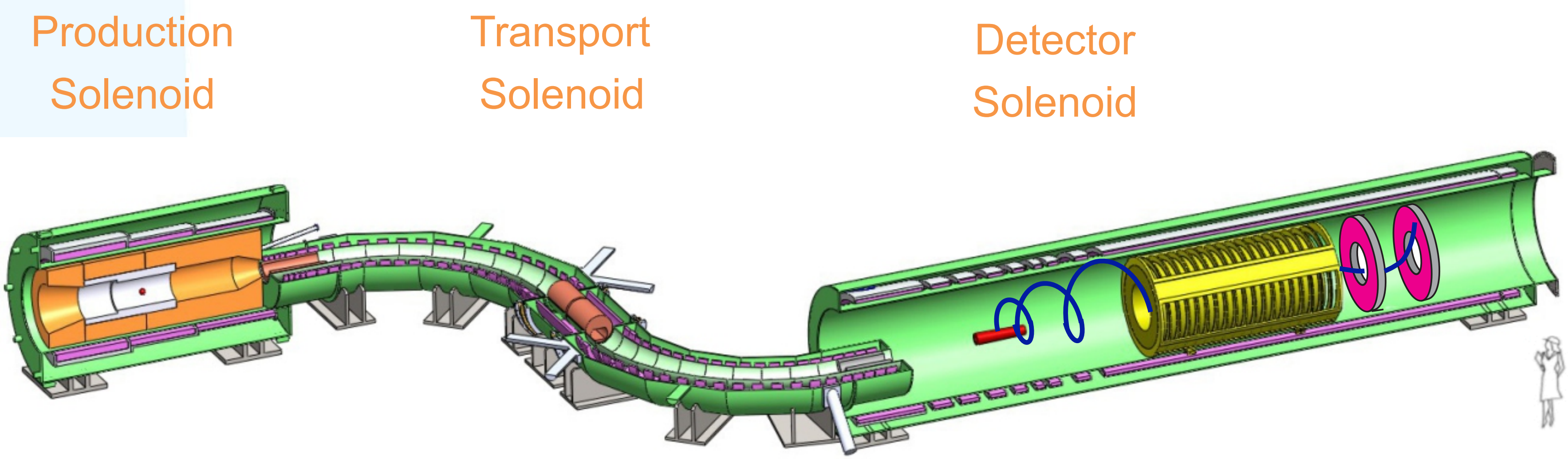


Transport Solenoid:

Captures π- and subsequent μ-; momentum- and sign-selects beam

- Consists of 3 solenoid systems

Mu2e Experimental Apparatus



Detector Solenoid:
Upstream – Al. stopping target, Downstream – tracker, calorimeter
(not shown – cosmic ray veto system, extinction monitor, target monitor)

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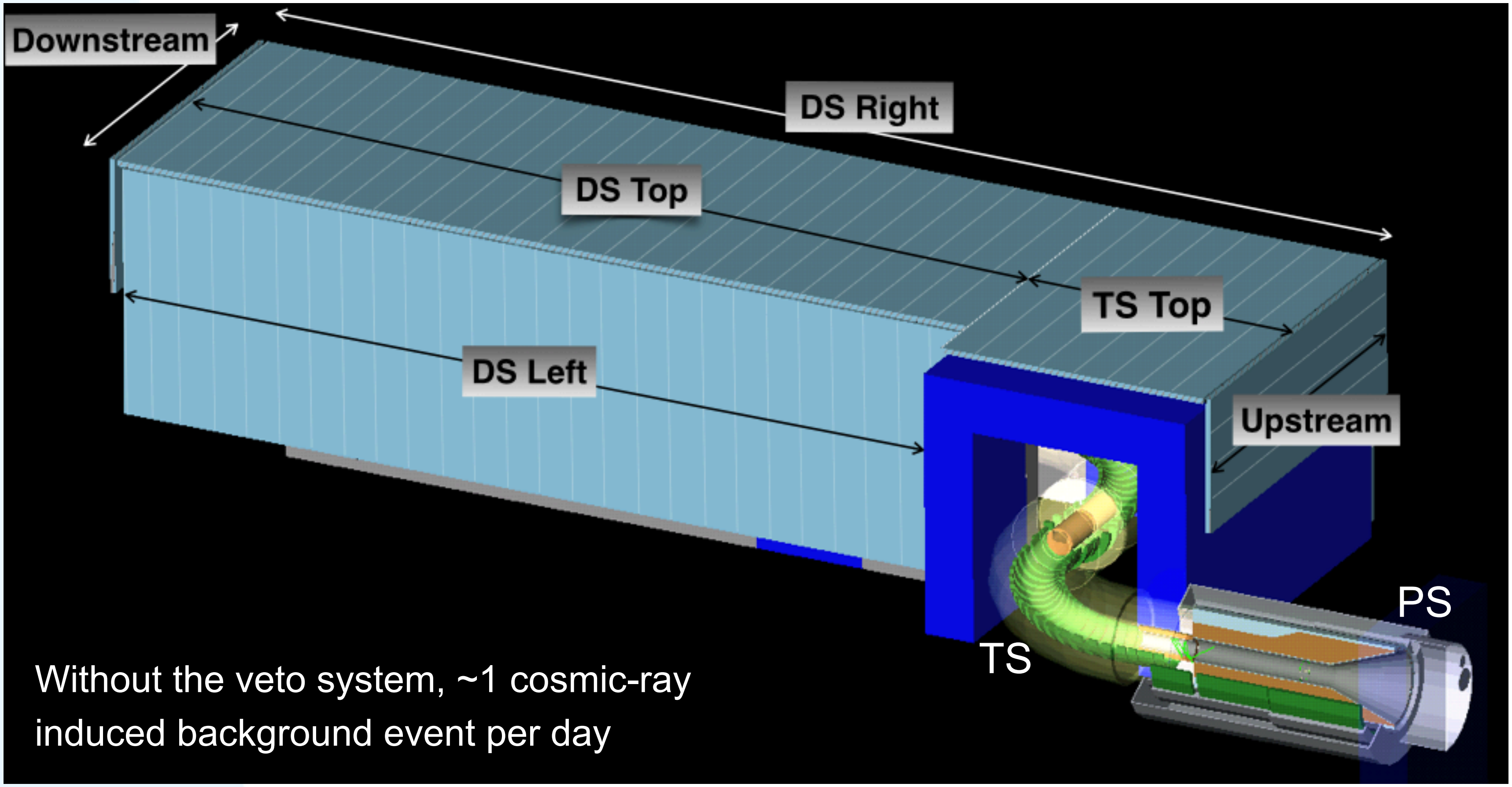
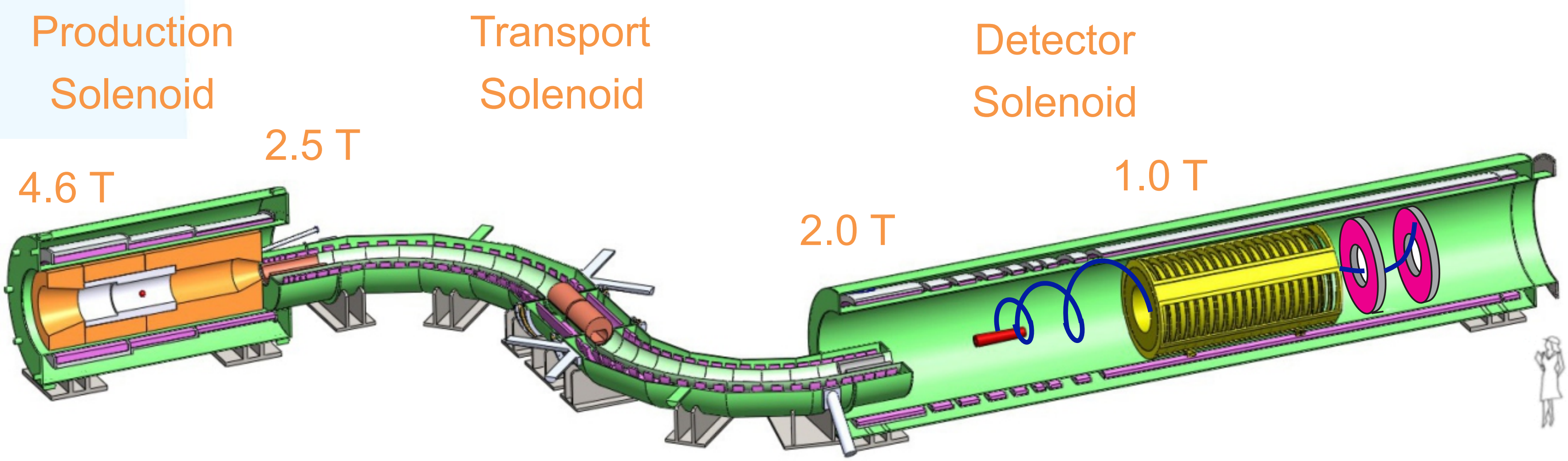
Mu2e Experimental Apparatus



- CR-Veto system covers entire DS and half the TS

Mu2e Experimental Apparatus



Graded fields important to suppress backgrounds, to increase muon yield, and to improve geometric acceptance for signal electrons

- Consists of 3 solenoid systems

Mu2e Experimental Hall

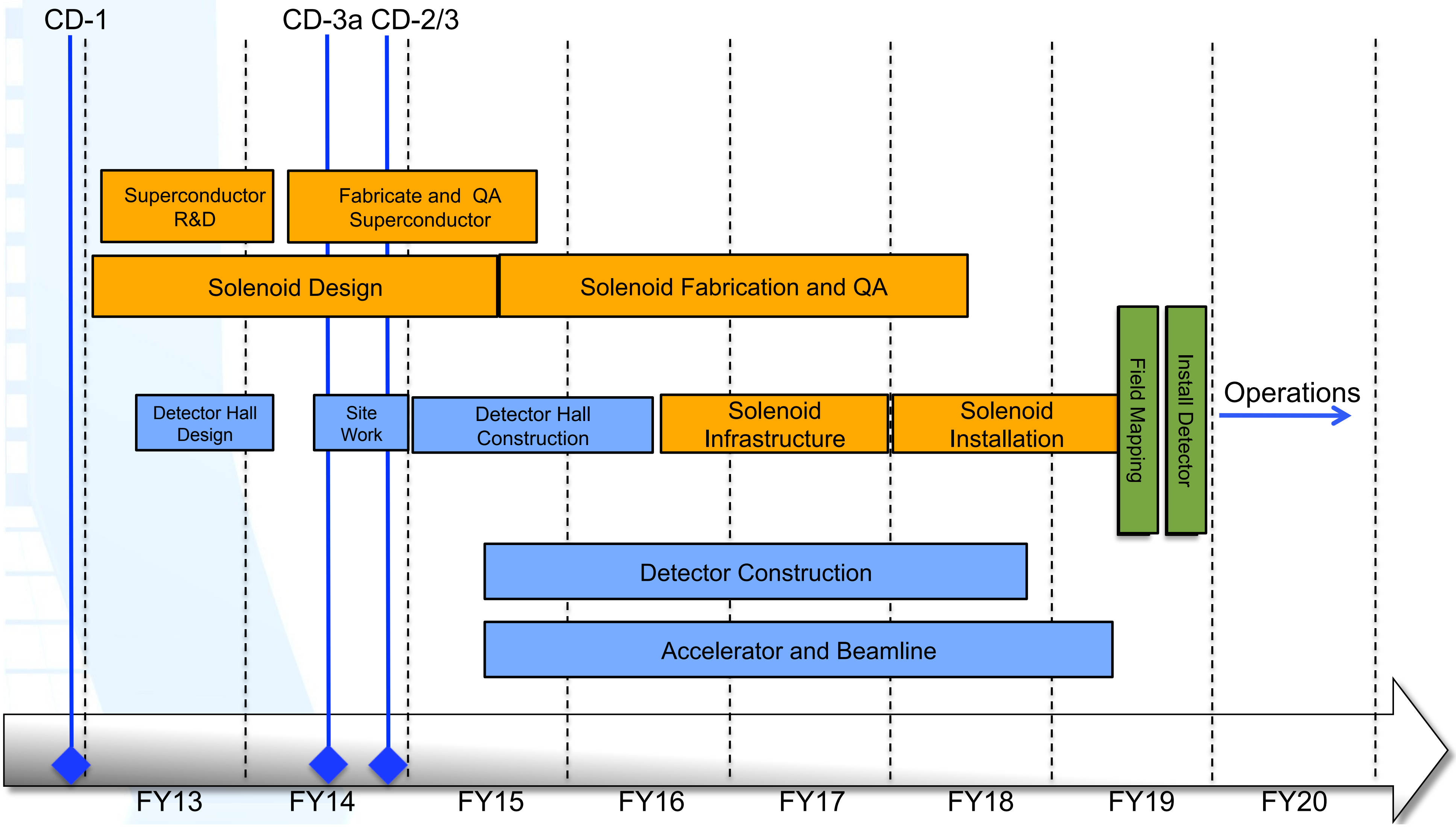
Graphic of proposed Mu2e Detector Hall

- Have received 100% drawings from A&E firm
- Scheduled to break ground Fall 2014

Mu2e Status

- CD-0 in November 2009
- NEPA Categorical Exclusion June 2012
- CD-1 in July 2012
- Scheduled CD-3a in FY2014-Q3
  - Order production lengths of solenoid superconductor (long lead item)
- Scheduled CD2/3 in FY2014-Q4
  - Start on building, proceed expeditiously with solenoid fabrication

Mu2e Schedule



- Critical path: Solenoid design, construction, commissioning

Mu2e Progress

Mu2e 2013 Goals

- Obtain R&D lengths of all conductor types required to fabricate solenoids.

- Develop a Reference Design for the solenoids and solicit bids from industry for their Final Design & Fabrication.

- Complete necessary studies to specify baseline design in preparation for CD-2
  - Detector down selects
  - Shielding designs
  - Detector R&D and test beam studies
  - Building drawings

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Thanks to excellent support from all divisions at Fermilab!

Thanks to our talented and dedicated collaboration!

Mu2e Recent Progress : Conductor R&D

- Our solenoids require four different conductors
  - Production solenoid (PS)
  - Transport solenoid (TS)
  - Detector solenoid x2 (DS-1, DS-2)

- To produce conductor, 3 main steps
  - Superconducting strand
  - Rutherford cable
  - Extruded superconductor

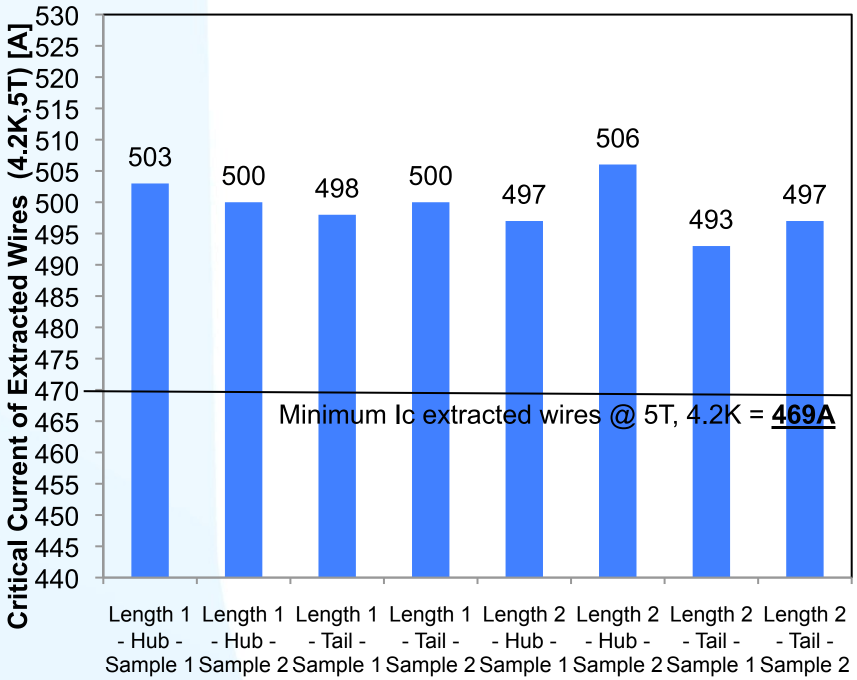
- Awarded contracts to vendors in early 2013 to produce R&D quantities of each conductor

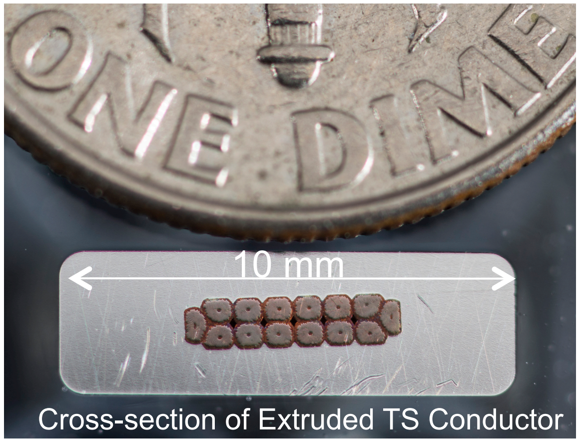
Mu2e Recent Progress : Conductor R&D

- Vendors making excellent progress.
- Conductor R&D campaign nearly complete.
- We are ready to place Production orders for TS and DS conductors. Vendor iterating on PS conductor.

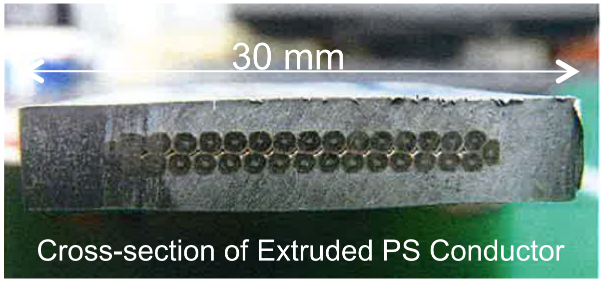
Conductor Type	Strand	Cable	Final extrusion	Shipped
PS	meets spec	meets spec	Needs work	here
TS	meets spec	meets spec	meets spec	here
DS-1	meets spec	meets spec	meets spec	here
DS-2	meets spec	meets spec	meets spec	here

Mu2e Recent Progress : Conductor R&D





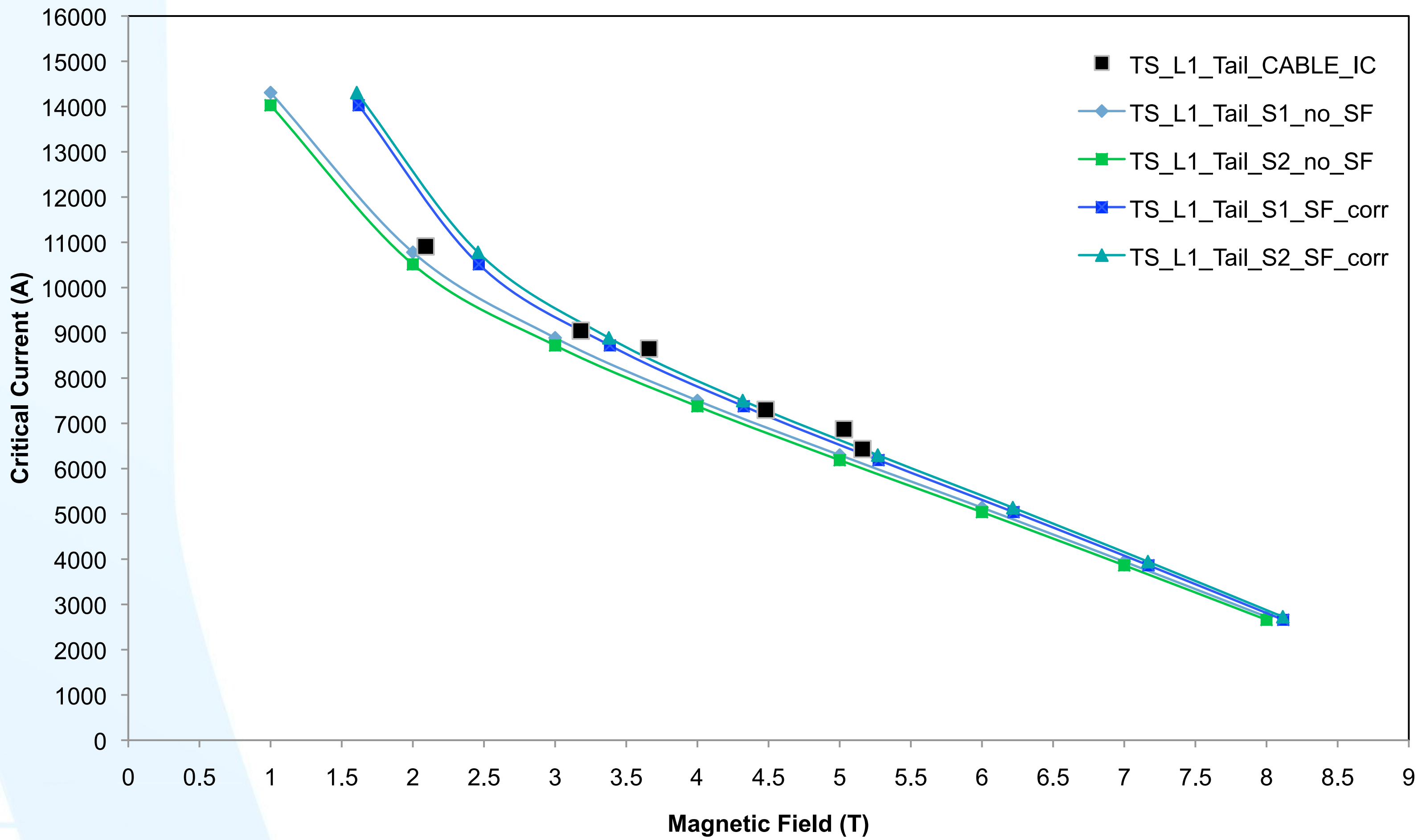
Cross-section of Extruded TS Conductor



Cross-section of Extruded PS Conductor

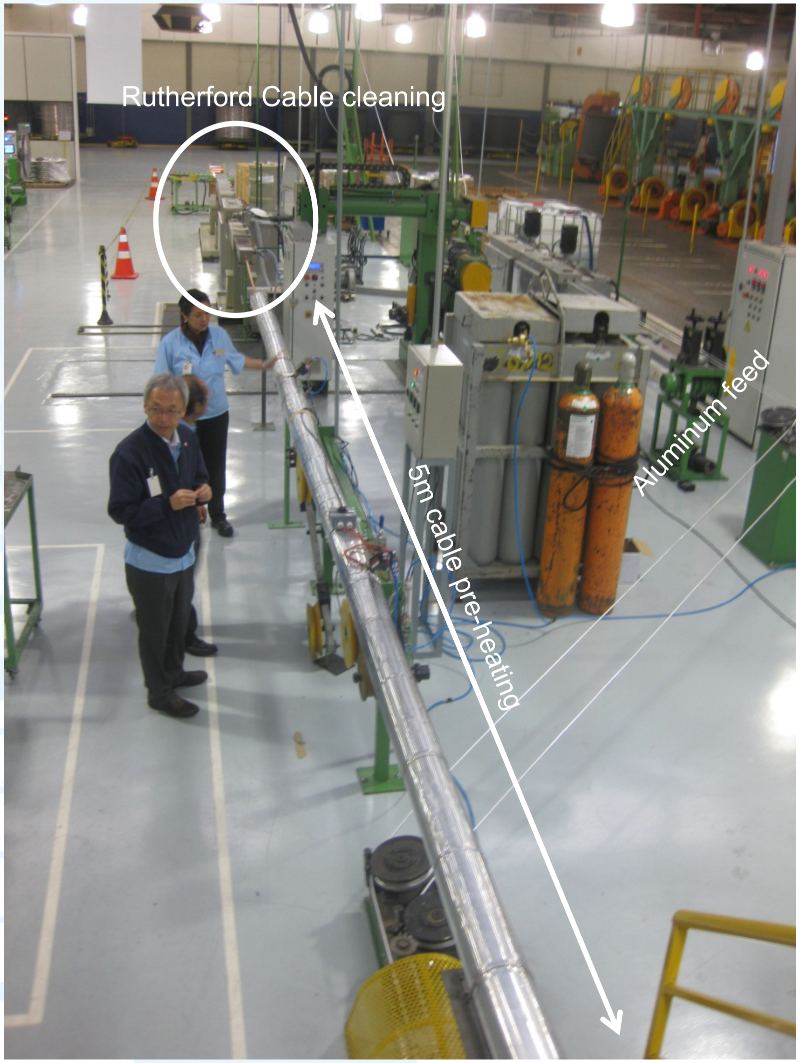
- Have established a thorough QA program
  - Facilities and personnel provided by FNAL Superconducting Materials Department

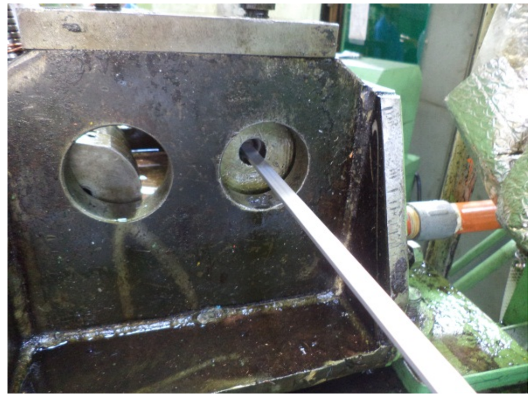
Mu2e Recent Progress: Conductor R&D

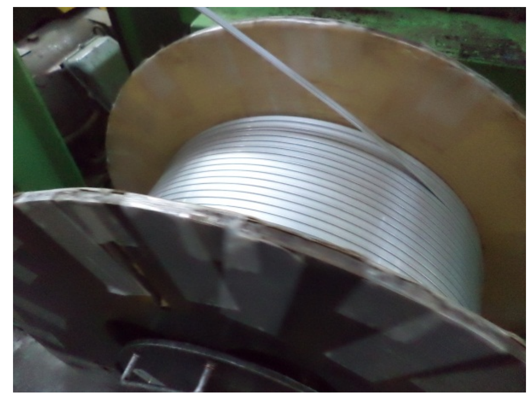


- Additional tests performed at INFN Genoa
  - Also engaged with vendor to produce prototype TS coil

Mu2e Recent Progress : Conductor R&D







- Have established a good relationship with the vendors

Mu2e Recent Progress : Solenoid Design

- Have developed a mature reference design
  - Complete solid model
  - Detailed interface specifications
  - Detailed technical specifications and tolerances
- Required significant sustained effort
  - ~20 FTE of engineering and design effort for last 1yr
  - Significant simulation effort to verify physics capabilities
- Subject to several external reviews
  - Independent Design Review
  - Cooling Review
  - Acquisition Review

Mu2e Recent Progress : Solenoid Design

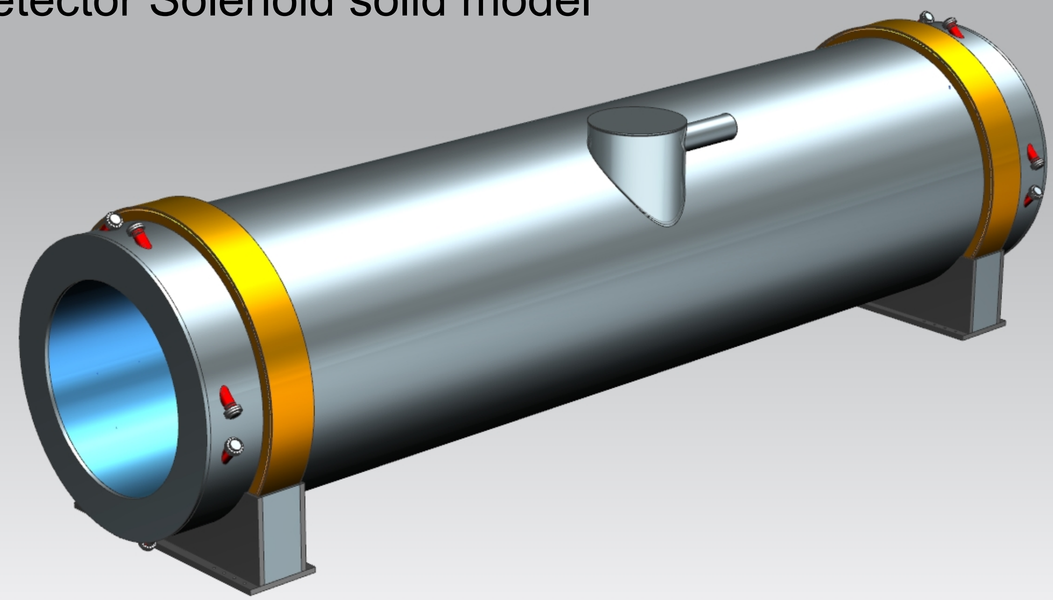
	PS	TS	DS
Length (m)	4	13	11
Diameter (m)	1.7	0.4	1.9
Field @ start (T)	4.6	2.5	2.0
Field @ end (T)	2.5	2.0	1.0
Number of coils	3	50	11
Conductor (km)	10	44	15
Operating current (kA)	10	3	6
Stored energy (MJ)	80	20	30
Cold mass (tons)	11	26	8

- Design performance quantified using a variety of simulation and modeling tools
  - Fermilab, LBNL, Boston

Mu2e Recent Progress : Solenoid Design

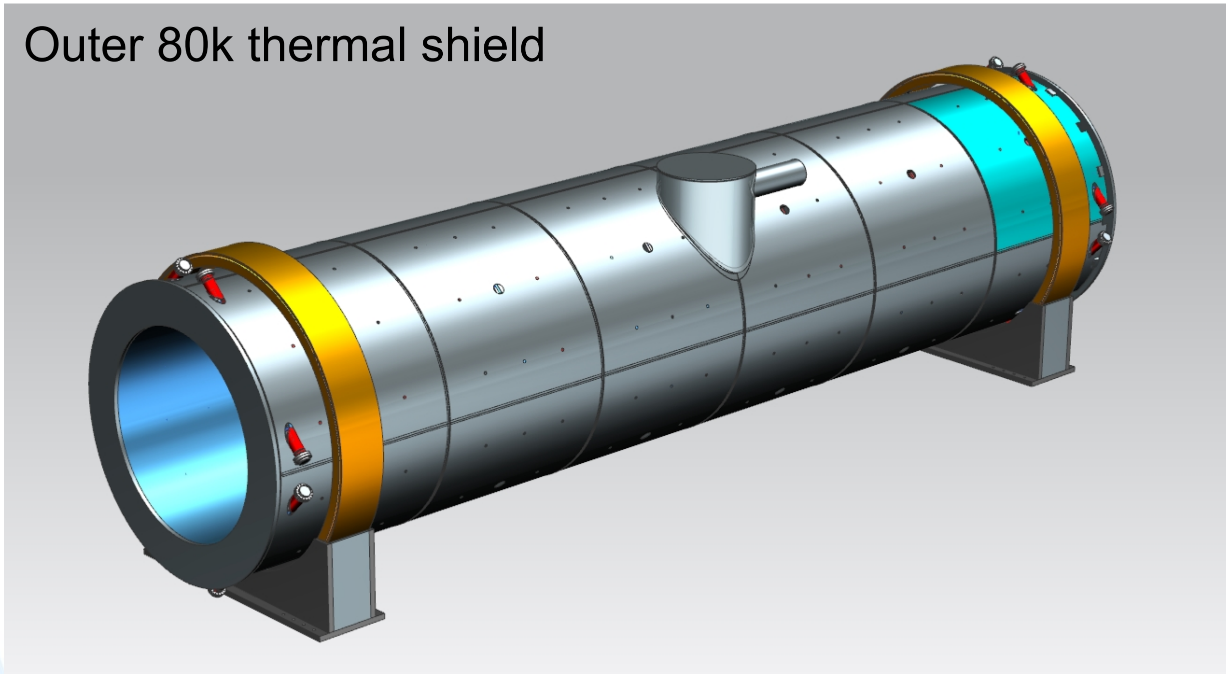
- Have solicited bids from industry
  - Response from 5 world-class vendors
  - Have visited all 5 vendors
  - Bids due 12 May, ahead of CD-2 reviews

Detector Solenoid solid model



Mu2e Recent Progress : Solenoid Design

- Bids from industry due 12 May



Mu2e Recent Progress : Solenoid Design

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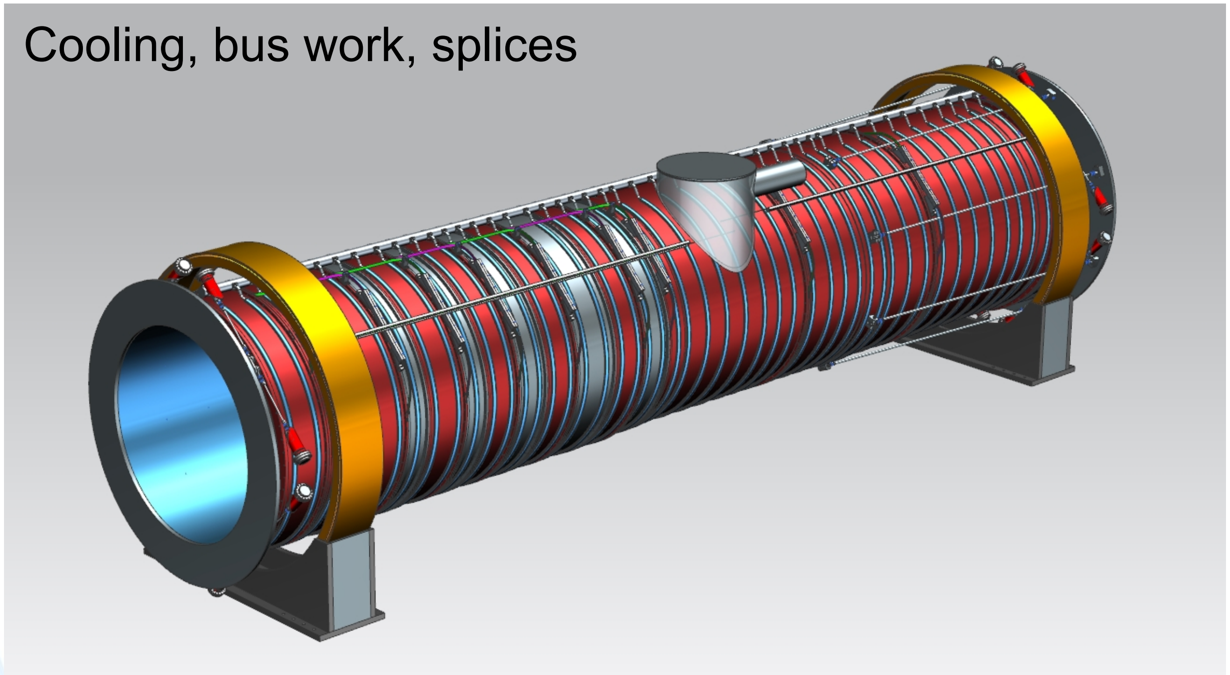
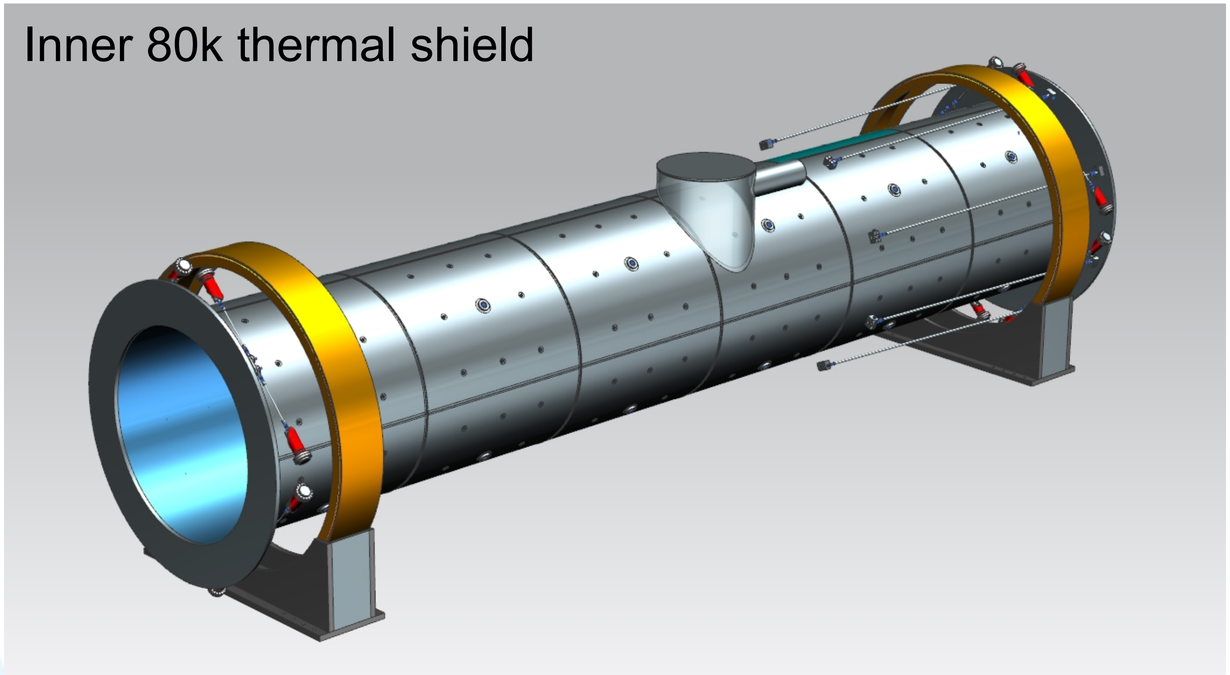


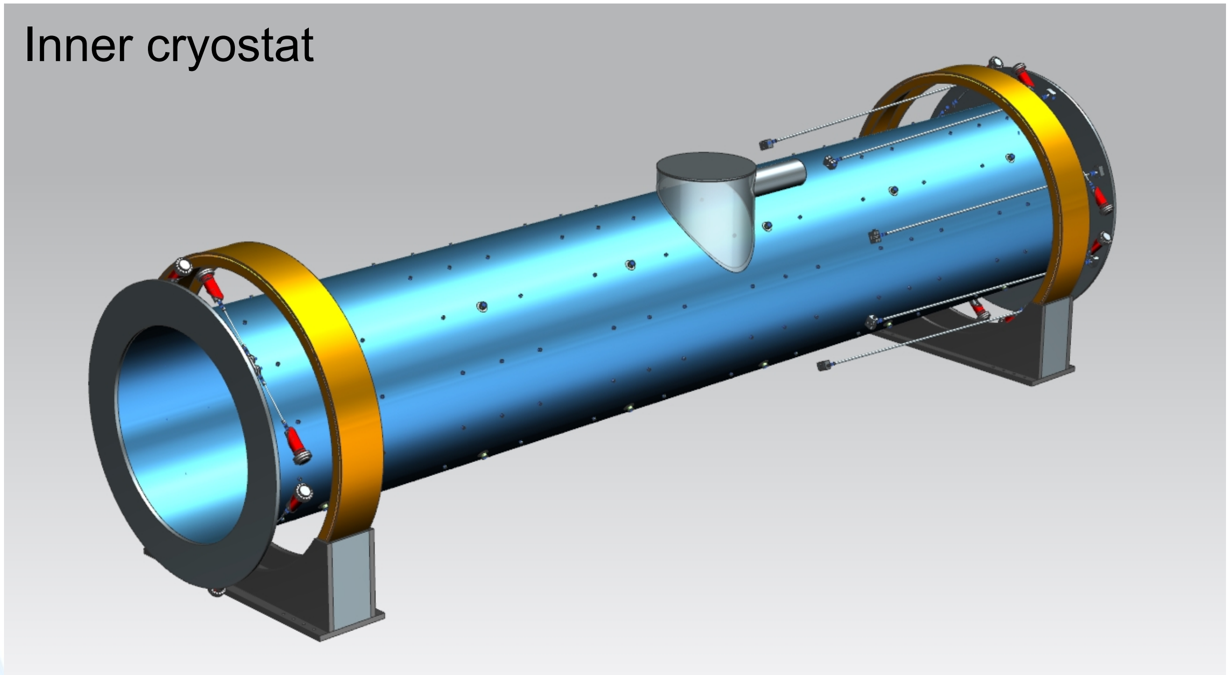
Mu2e Recent Progress : Solenoid Design

- Bids from industry due 12 May



Mu2e Recent Progress : Solenoid Design

- Bids from industry due 12 May



Mu2e Recent Progress : Down Selects

- Together with collaboration, made design choices affecting key detector elements
  - Tracker
  - Calorimeter
  - Extinction Monitor

Mu2e Recent Progress : Down Selects

- Together with collaboration, made design choices affecting key detector elements
  - Tracker
    Duke, Fermilab*, Houston, INFN Lecce*, Rice, LBNL, CUNY
  - Calorimeter
    Caltech*, Fermilab, INFN Frascati*, Lecce, Pisa, Udine
  - Extinction Monitor
    Fermilab*, UC Irvine*, NIU, Purdue

Mu2e Recent Progress : Down Selects

- Together with collaboration, made design choices affecting key detector elements
  - Tracker
    Duke, Fermilab*, Houston, INFN Lecce*, Rice, LBNL, CUNY
  - Calorimeter
    Caltech*, Fermilab, INFN Frascati*, Lecce, Pisa, Udine
  - Extinction Monitor
    Fermilab*, UC Irvine*, NIU, Purdue
- Enabled by Mu2e (art based) software and simulation package
  - Geant4, MARS, G4Beamline
  - Hit level detector simulation
  - Include full occupancy from beam-related activity
  - Full reconstruction algorithms employed

Mu2e Simulations

Institution	Name	Position	Topics	User/Developer
BU	E. Barnes	PD	Calibration, Bgd	U
BU	J. Miller	SR	Backgrounds	U
BU	V. Logoshenko	SR	Backgrounds	UD
Caltech	B. Echenard	PD	Calorimeter, Reco	UD
Fermilab	A. Gaponenko	WF	Background Coord.	UD
Fermilab	R. Bernstein	SR	Backgrounds	UD
Fermilab	R. Coleman	SR	Shielding Designs	UD
Fermilab	V. Khalatian	GS	Shielding Designs	U
Fermilab	K. Knoepfel	PD	Geometry, Bgd	UD
Fermilab	R. Kutschke	SR	Head of Software	UD
Fermilab	P. Murat	SR	Calorimeter, Reco	U
Fermilab	V. Rusu	SR	Tracker, Reco	UD
INFN Lecce	G. Tassieli	PD	Reconstruction	UD
INFN Lecce	F. Ignagtov	SR	Reconstruction	U
INFN Lecce	G. Onorato	PD	Backgrounds	UD
INFN Pisa	G. Pezzulo	GS	Calorimeter, Reco	U
UC Irvine	Z. You	PD	Ext. Monitor	UD
NIU	D. Hedin	SR	Shielding Designs	U
NIU	Z. Hodges	GS	Stopping Target	U
NIU	A. Yurkewicz	PD	Stopping Target	U
Rice	A. Chandra	PD	Stopping Target	U
LBNL	D. Brown	SR	Reconstruction	UD
LBNL	M. Lee	PD	Reconstruction	UD
U Virginia	Y. Oksuzian	PD	Shielding, CR Veto	U
U Virginia	M. Frank	PD	Shielding, CR Veto	U
U Virginia	R. Ehrlich	PD	CR-induced Bgd	UD
York	K.Lynch	SR	GEANT Physics tests	UD

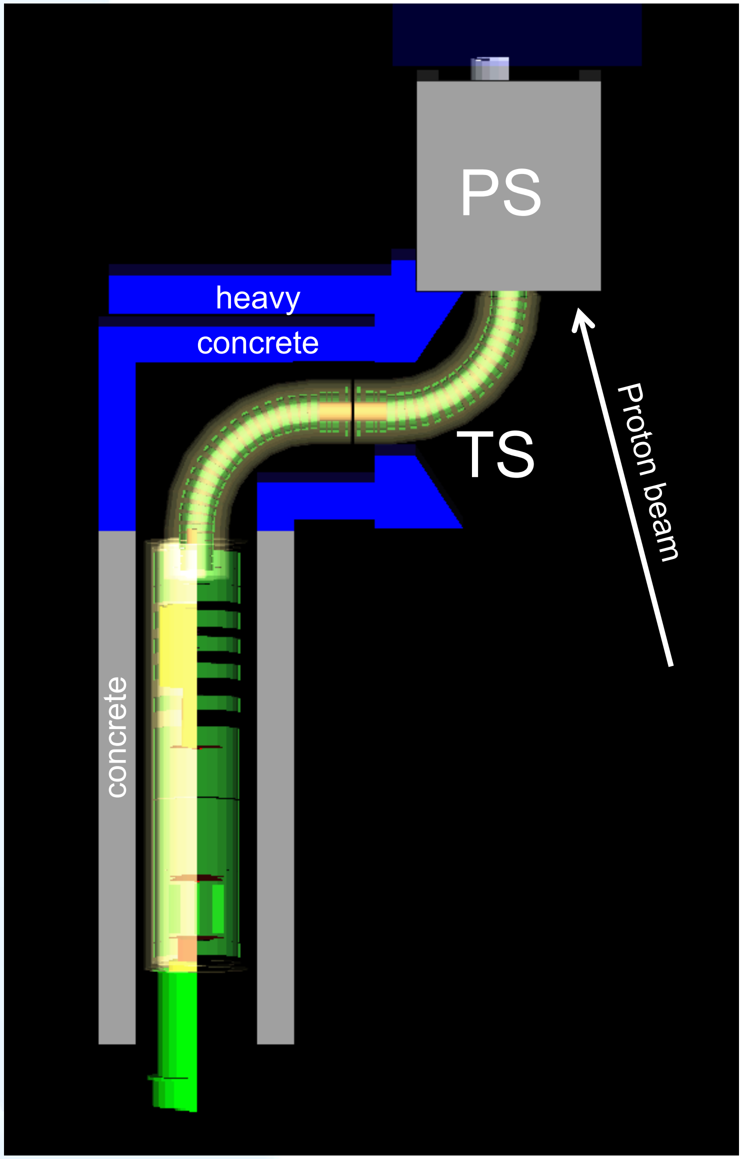
- About 20% of collaboration actively engaged in simulation

Mu2e Simulations (last 12 months)

Topic	Events Generated
Beamline Optimizations	1000 M
Tracker and Tracking	70 M
Calorimeter	60 M
Shielding Designs	4000 M
CR Veto	100000 M
Miscellaneous	1400 M
Total	107 B

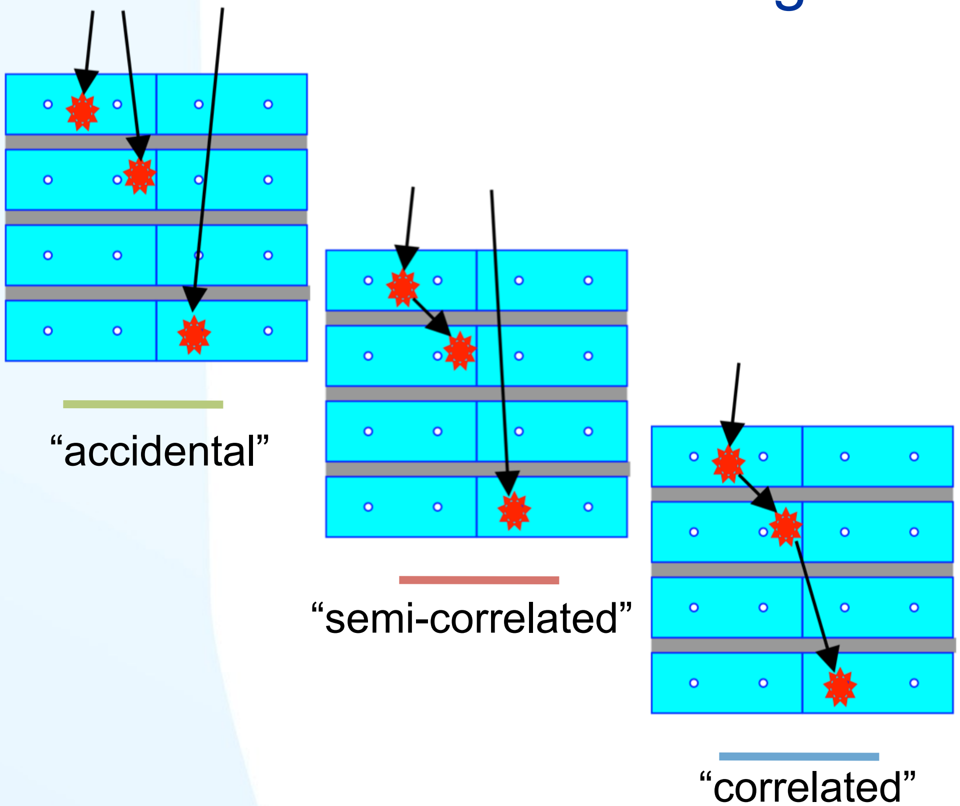
- 1000+ core cpu farm with Mu2e as primary users provided by Fermilab Scientific Computing Division
- Also make use of opportunistic cycles on Grid

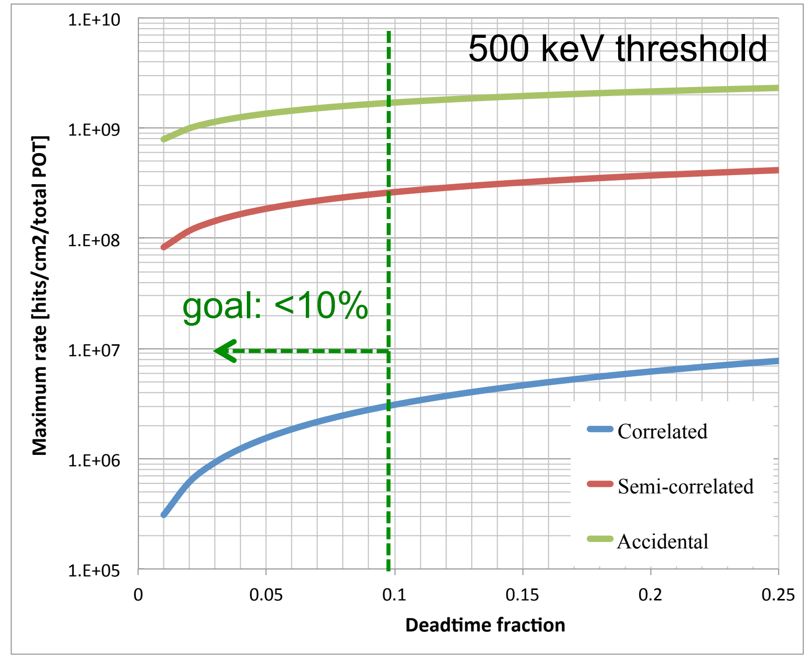
Mu2e Recent Progress : Shielding Designs



- Have identified a cost-effective shielding solution
  - Initiated Neutron Task Force (July 2012)
  - Led by R.Coleman (FNAL) D.Hedin (NIU)
  - Simulation intensive
    - Compare GEANT and MARS
  - Non-trivial optimization
    - Currently on v14

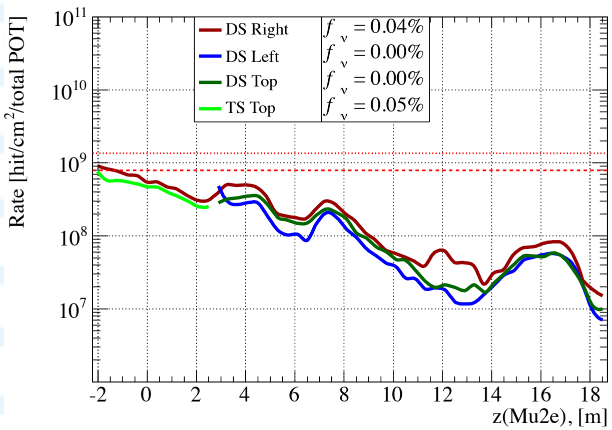
Mu2e Recent Progress: Shielding Designs



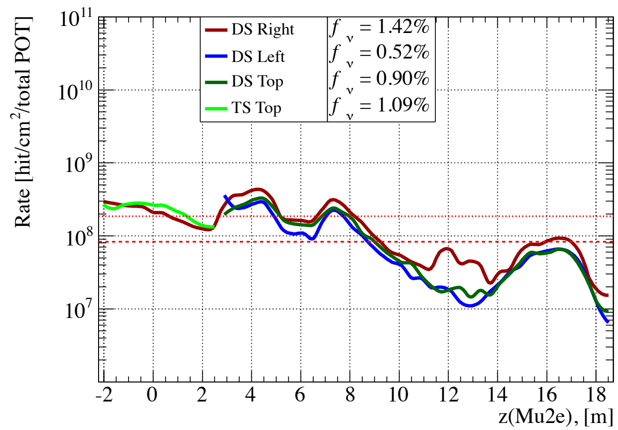


- We needed to understand contributions from accidentals and correlated-accidentals
  - For neutrons and photons as a function of time, energy, timing resolution, and read-out threshold

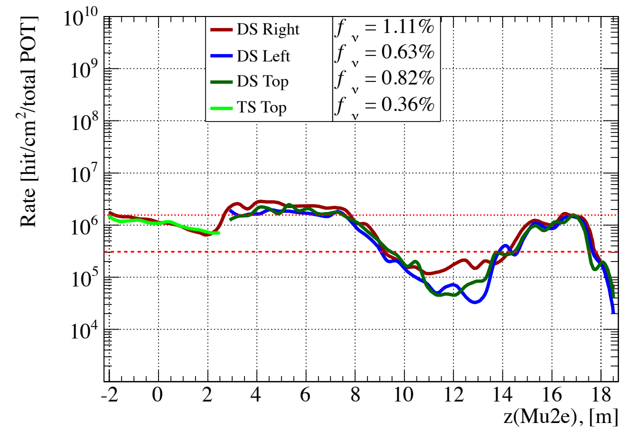
Mu2e Recent Progress: Shielding Designs



accidental



semi-correlated



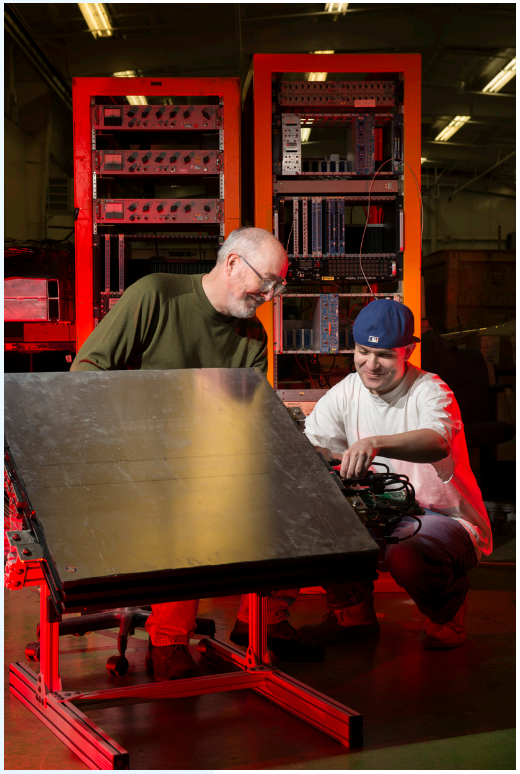
correlated

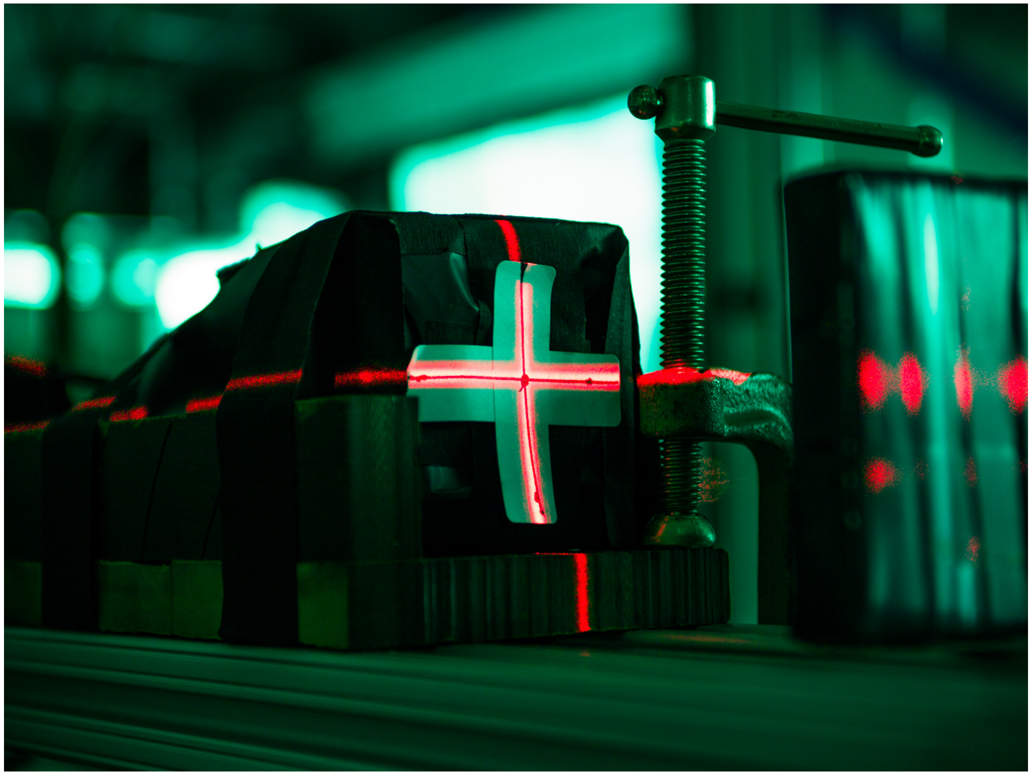
- Total dead time from neutron/photon “noise” = 8%
  - For 500 keV readout threshold
  - Increasing to 1 MeV reduces to 2%
  - In progress: Cross-check with a separate physics generator (MARS)

Mu2e Recent Progress : Test Beams

- Test beam efforts for Cosmic-Ray Veto and Extinction Monitor systems completed in September at Fermilab.
- Joint US-Japan effort to measure products of muon capture on aluminum (AlCap) completed Run-1 in December at PSI.
- Calorimeter test beam scheduled for February to test different crystals and photo-sensors.
- Variety of radiation hardness tests.

Test Beam – September 2013

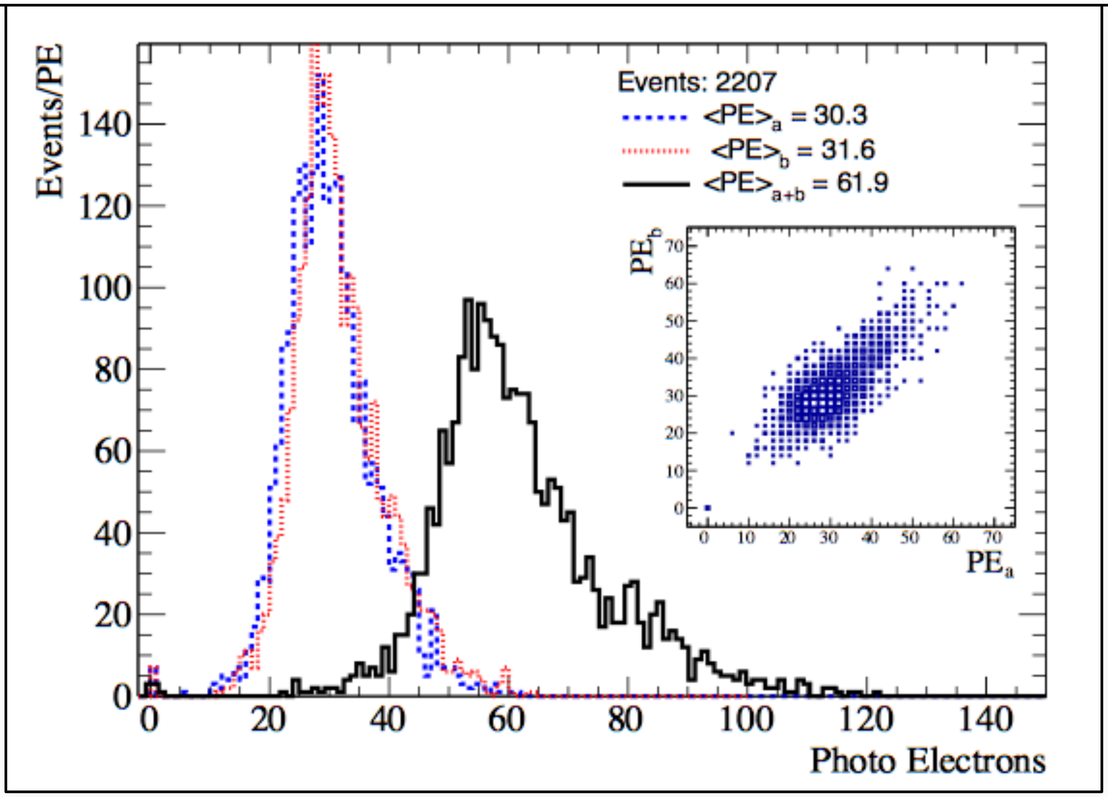




- Cosmic Ray Veto – SiPM, WLS, and component prototype tests
- Upstream Extinction Monitor – conceptual demonstration

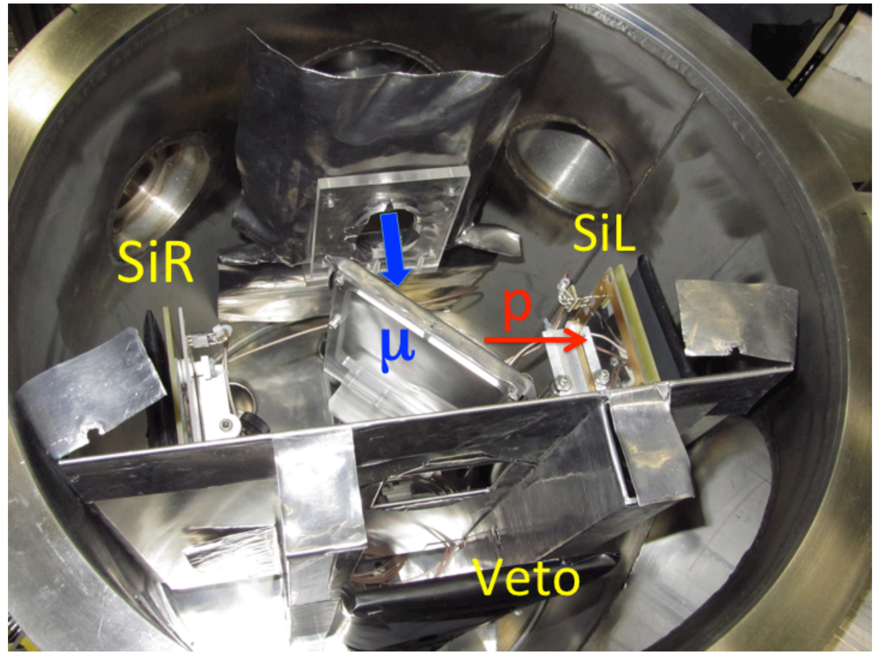
Test Beam – September 2013 Results

Typical light yield from CRV counter prototype – 20 cm from RO end



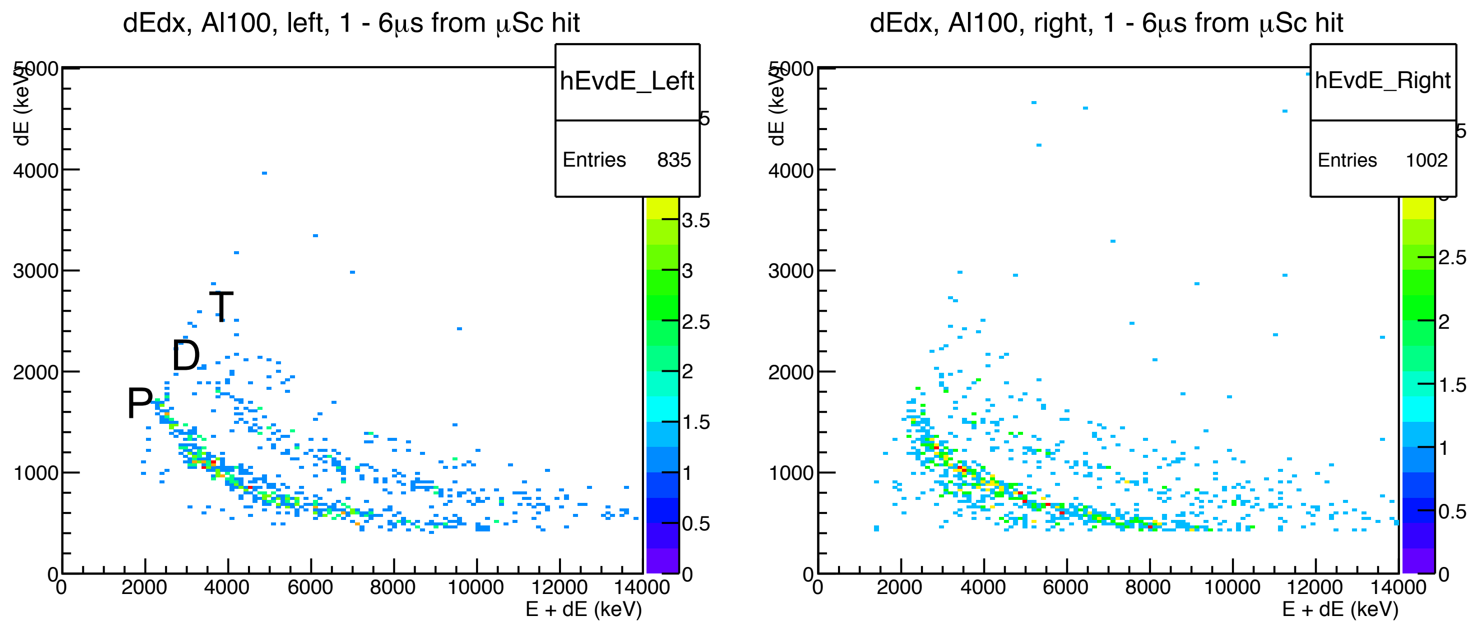
- Achieves veto efficiency >99% at 2.5m from RO
  - want more light to allow for SiPM failure, 8y lifetime
  - will move from 1mm WLS fiber to 1.4 mm

Test Beam – December 2013



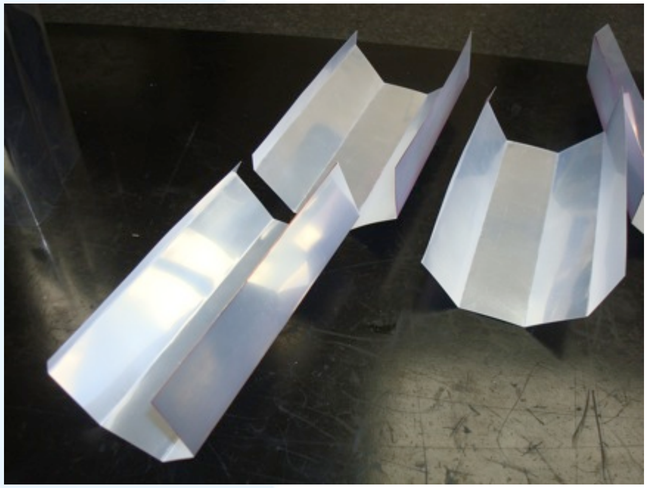
- AlCap – measurement of products of muon captures on aluminum
  - Joint Mu2e/COMET effort
  - Took data at PSI 26Nov – 23Dec

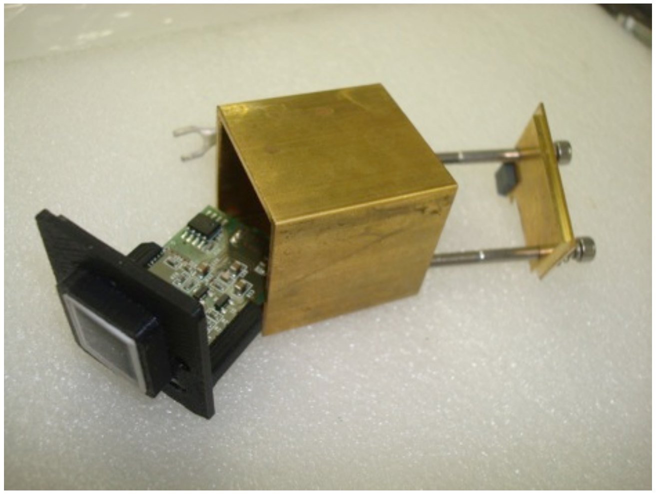
Test Beam – December 2013 Results

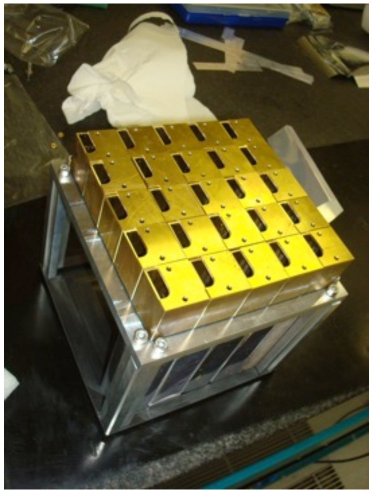


- Preliminary AlCap results
  - Analysis ongoing, but proton, deuteron lines clear

Test Beam – February 2013 Preparations

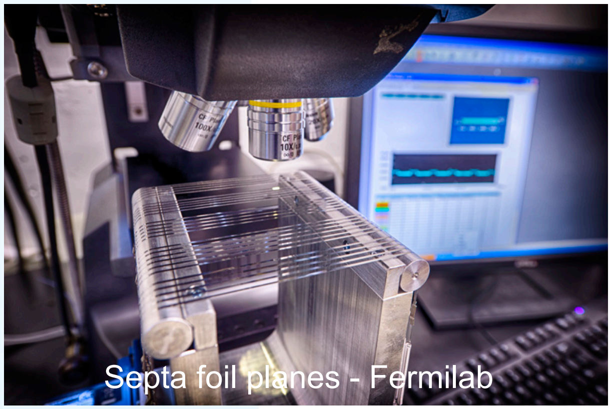






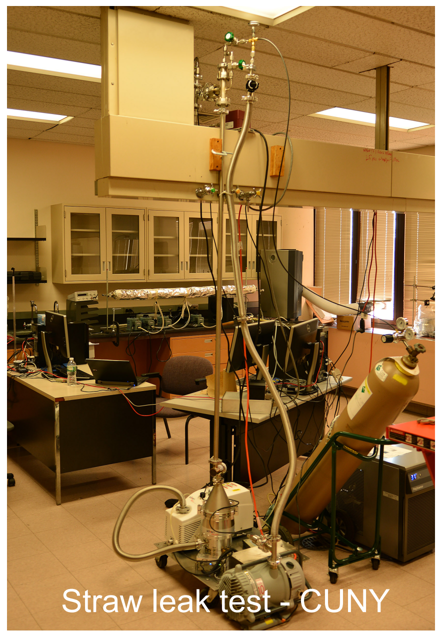
- Test beam (5 -500 MeV e-) in Frascati in Feb.

Mu2e Recent Progress: Other R&D


Septa foil planes - Fermilab


CRV Manifolds – U.Virginia

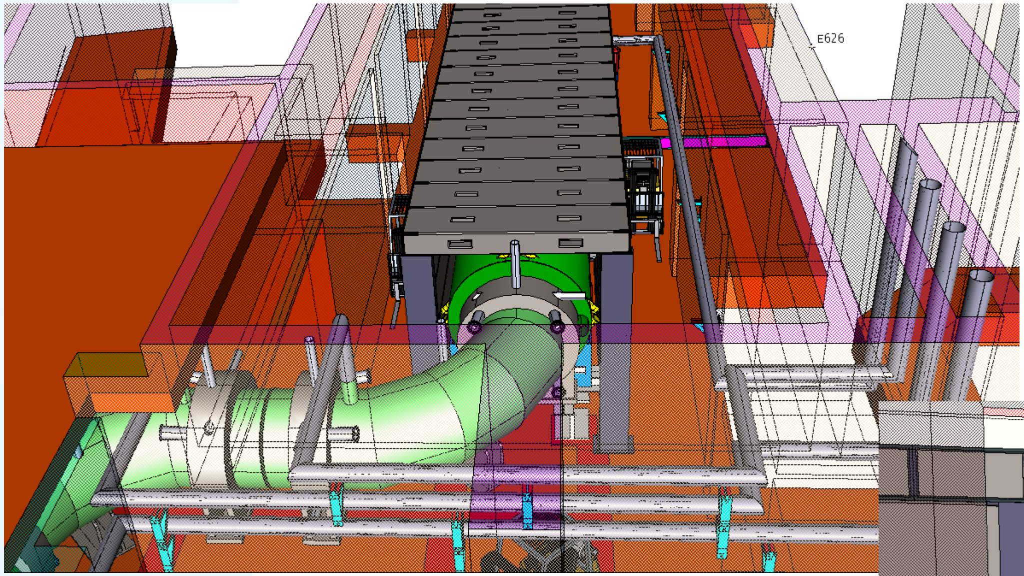

2x4 Straw test - Fermilab

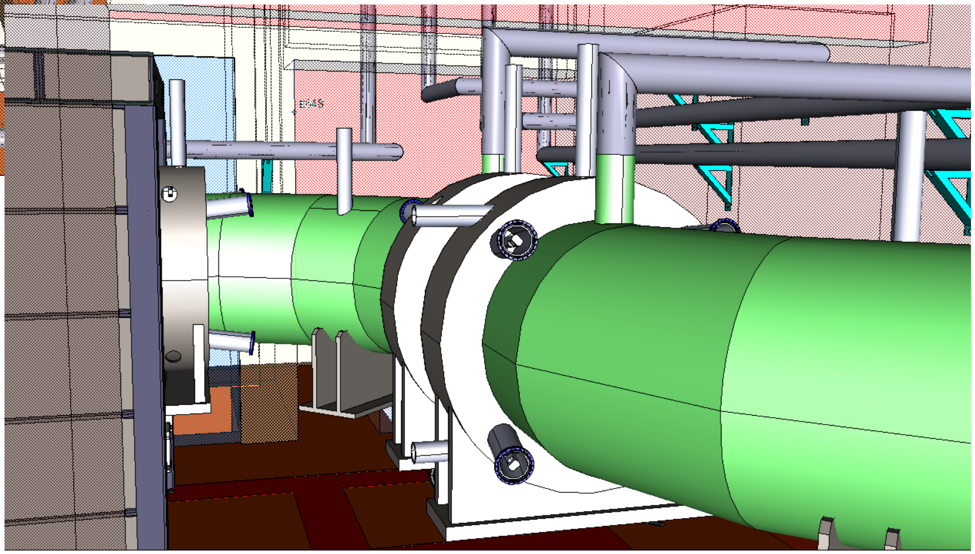

Straw leak test - CUNY

Custom pulsed power supply for fatigue tests on prototype production target - RAL

- Active R&D campaign across project

Mu2e Recent Progress : Details!





- Weekly meetings to recognize & reconcile interface issues

Mu2e Challenges

Mu2e Challenges

- Maintain solenoid schedule
  - CD-3a review in June (after P5)
  - Aim to make PS/DS design awards this summer
- Finish preparations for CD-2/3 review
  - Aim to have review in summer of FY2014
- Determine viability of radiatively cooled W production target
  - Ongoing R&D at RAL
  - Potential oxidation issues if pressure > 1e-6 mbar
  - Fall-back, water-cooled target ($+1M)
- Develop photosensors for BaF2 calorimeter
  - Ongoing R&D at Caltech/JPL/RMD
  - Fall-back being developed

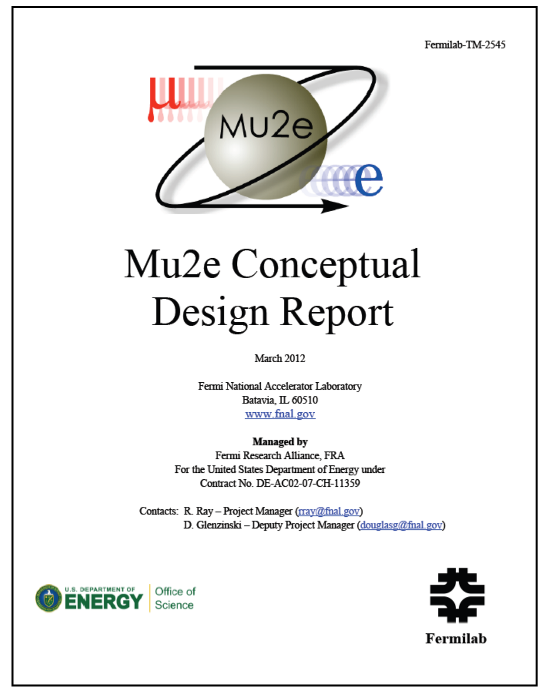
In Closing

Conclusions

- Mu2e offers compelling discovery sensitivity across a broad swath of BSM parameter space.
  - A unique incisive probe of BSM physics
- Solenoid designs mature
  - Conductor R&D program successful
  - Vendor bids for design/build PS, DS due in mid-May
- Significant progress in defining design of the baseline apparatus – will be ready for CD-2/3 in summer FY2014.
- Building design complete – ready to break ground in Fall 2014.

More Information about Mu2e

- Conceptual Design Report
  - http://arXiv.org/abs/1211.7019
- Experiment web site:
  - http://mu2e.fnal.gov


Fermilab-TM-2545

Mu2e

Mu2e Conceptual Design Report

March 2012

Fermi National Accelerator Laboratory
Batavia, IL 60510
www.fnal.gov

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Fermi Research Alliance, FRA
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U.S. DEPARTMENT OF ENERGY | Office of Science

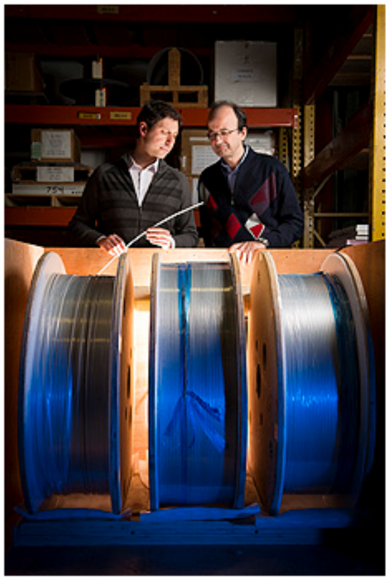
Fermilab

Backup Slides

Mu2e in the news

Feature

Mu2e superconducting cable prototype successful



Vito Lombardo and Giorgio Ambrosio lead the development of the Mu2e transport solenoid. In a recent test, the prototype superconducting cable for the solenoid met every benchmark. *Photo: Reidar Hahn*

Last month, members of the Technical Division conducted final tests on the first batch of prototype

December 16, 2013

Mu2e attracts magnet experts

By tapping into specialized knowledge around the world, the Mu2e collaboration will undertake a first-of-its-kind experiment.

By Andre Salles

PDF download

Related symmetry content

Feature: The muon guys: On the hunt for new physics

Feature: Through a muon's eyes

Elsewhere on the web

Mu2e experiment

Fermilab's Mu2e experiment is unlike anything ever attempted. So when the collaboration needed a first-of-its-kind magnet prototype built, they turned to an institution known for its magnet expertise: the Genoa section of the Italian Institute for Nuclear Physics, or INFN, located in the University of Genoa in Italy.

Earlier this year, INFN-Genoa became the sixth Italian institution to join the Mu2e collaboration, which now sports more than 150 members from 28 labs and universities in the United States, Italy and Russia. The team of magnet experts there has decades of experience working on high-energy physics experiments—they helped design and build magnets for BaBar at SLAC and, more recently, the CMS detector at CERN.

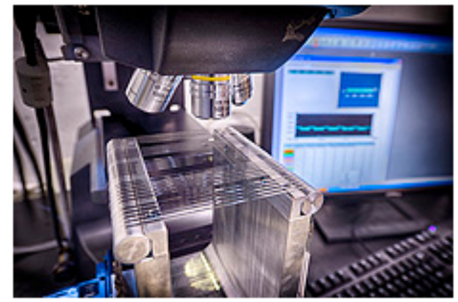
Now they're putting that knowledge toward building prototypes of the years-in-development magnets that will be used for for Mu2e, an experiment intended to study whether charged particles called leptons can change from one type to another. According to Doug Glenzinzki, the deputy project manager for Mu2e, the experiment's goal is to narrow down the possibilities for completing physicists' picture of the universe, by amassing evidence for one theory over others.

"We know the Standard Model is incomplete," Glenzinski says. "The number one goal of particle physics is to elucidate what a more complete model looks like. There are a lot of theories, and we are looking for data that tells us which is right."

It turns out, Glenzinski says, "charged lepton flavor violation"—the phenomenon Mu2e is being built to study—is a powerful way of

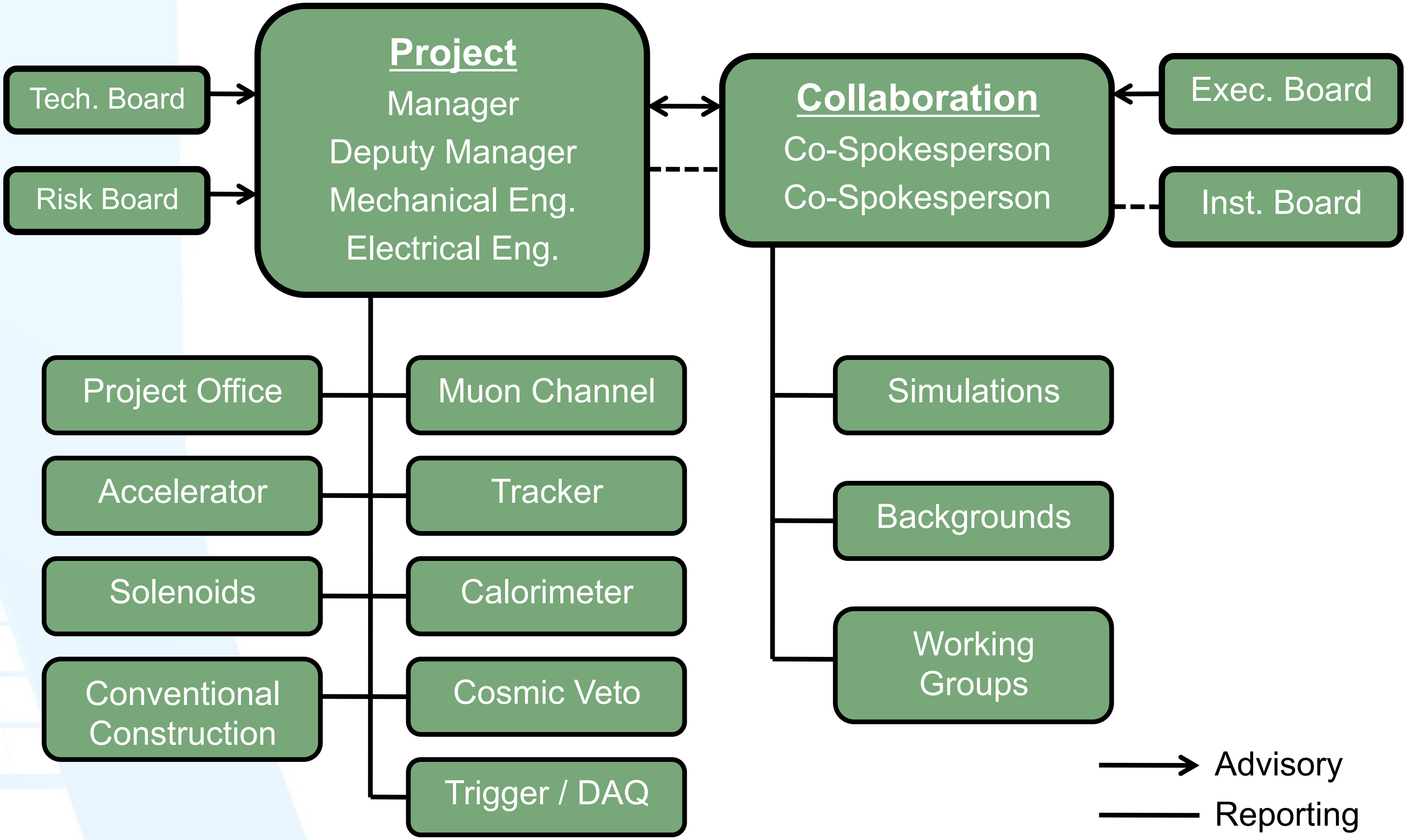
Photo of the Day

Toward better beam extraction



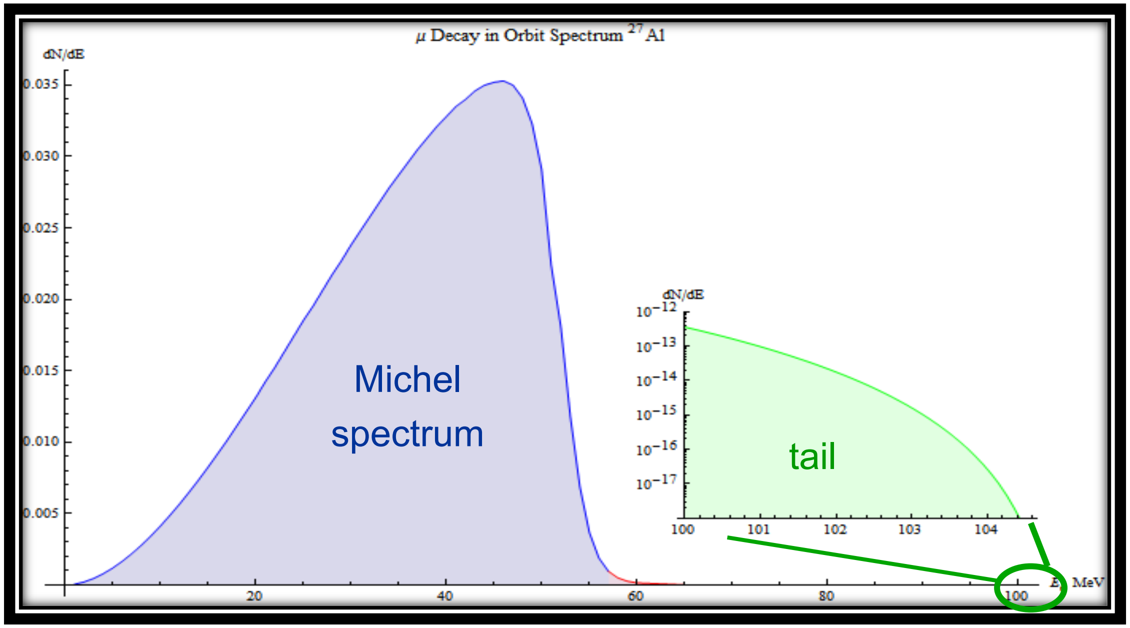
New projects bring to Fermilab new technological challenges and new solutions. One of those new technologies is the electrostatic septum made with very thin tungsten foils. Electrostatic septa are used in slow beam extraction to separate the circulating and extracted beams. At Fermilab, slow extraction has traditionally taken place as the beam is sent from the Main Injector to the Switchyard. In the standard technology, the septum plane is made as a layer of 100-micrometer tungsten wires. A challenge of the Mu2e project is slow extraction of protons with

Mu2e Organization



Mu2e Dominant Background Sources

- Decay-in-Orbit (DIO)
  - Intrinsic physics background from stopped muons decaying while in orbit around Al nucleus



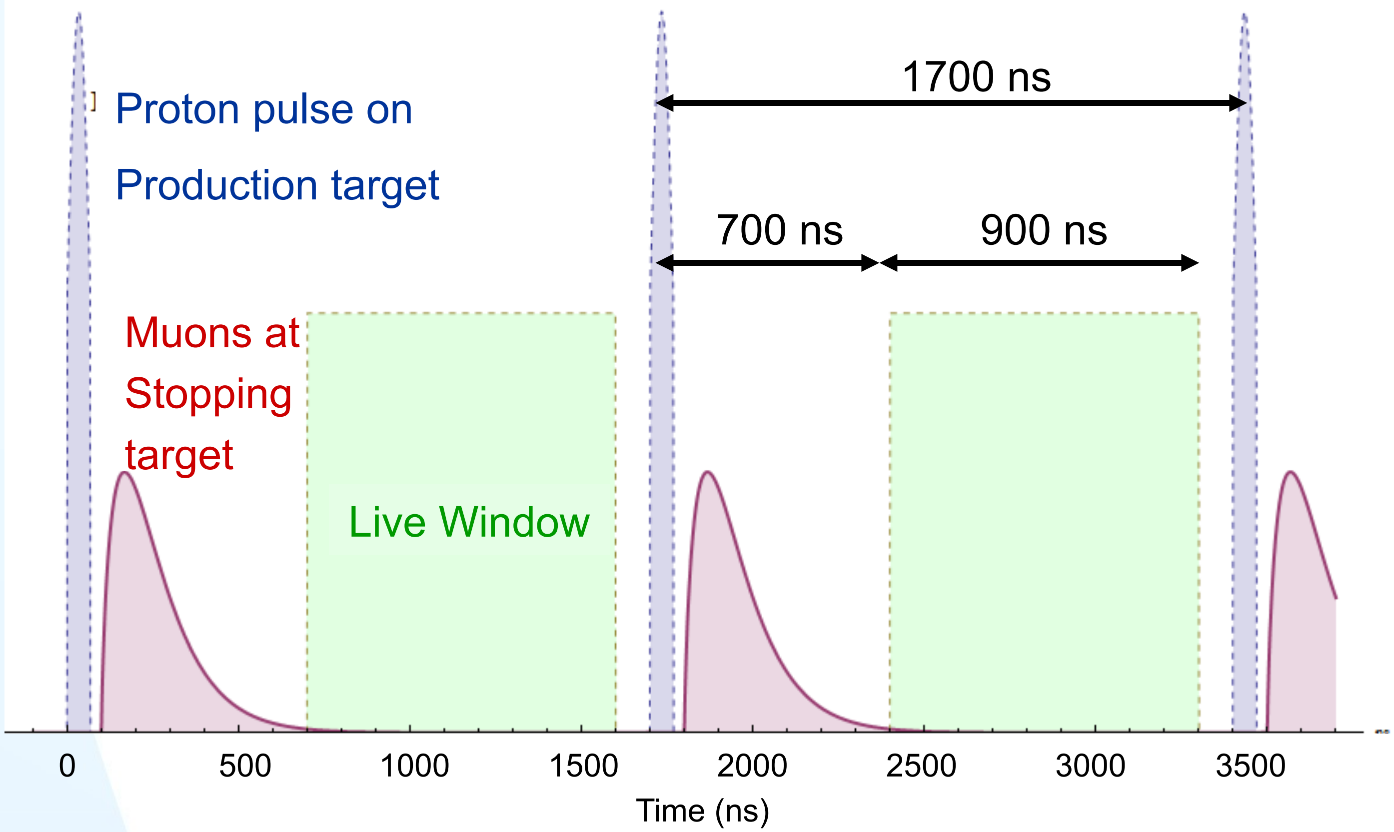
Electron energy in MeV

- Requires an excellent spectrometer resolution with small non-Gaussian tails

Mu2e Dominant Background Sources

- Radiative pion Capture (RPC)
  - Pions at Al target are promptly captured on nucleus
  - About 2% of the time a photon is radiated with a maximum energy ~ M_π
  - Main sources of pions at stopping target t >700 ns
    - Tails in proton distribution
    - Out-of-time protons
    - Anti-protons annihilating near Al target
- Requires narrow proton pulses, suppression of out-of-time protons, anti-proton absorber

Mu2e Pulsed Proton Beam



- Mu2e will use a pulsed proton beam and a delayed live gate to suppress prompt background

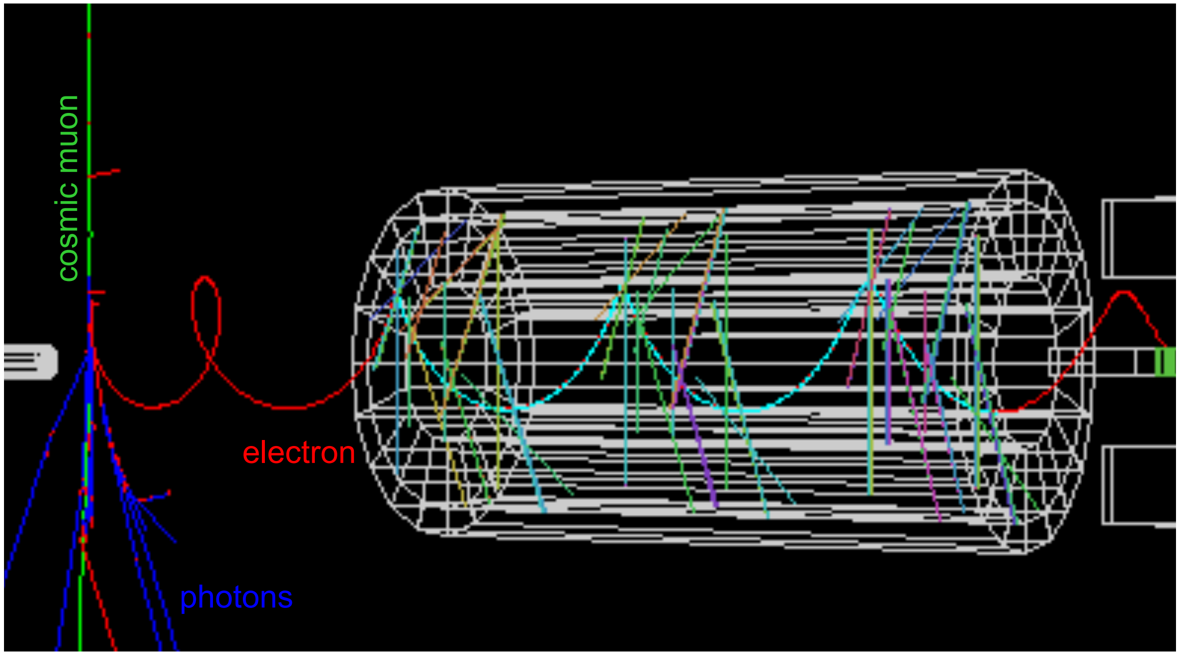
Mu2e Dominant Background Sources

- Radiative pion Capture (RPC)
  - Pions at Al target are promptly captured on nucleus
  - About 2% of the time a photon is radiated with a maximum energy ~ M_π
  - Main sources of pions at stopping target t >700 ns
    - Tails in proton distribution
    - Out-of-time protons
    - Anti-protons annihilating near Al target

- Requires narrow proton pulses, suppression of out-of-time protons, anti-proton absorber

Mu2e Dominant Background Sources

- Cosmic-Ray Induced
  - CR can create background events via scattering, decay, or material interactions
  - Get about one such event per day



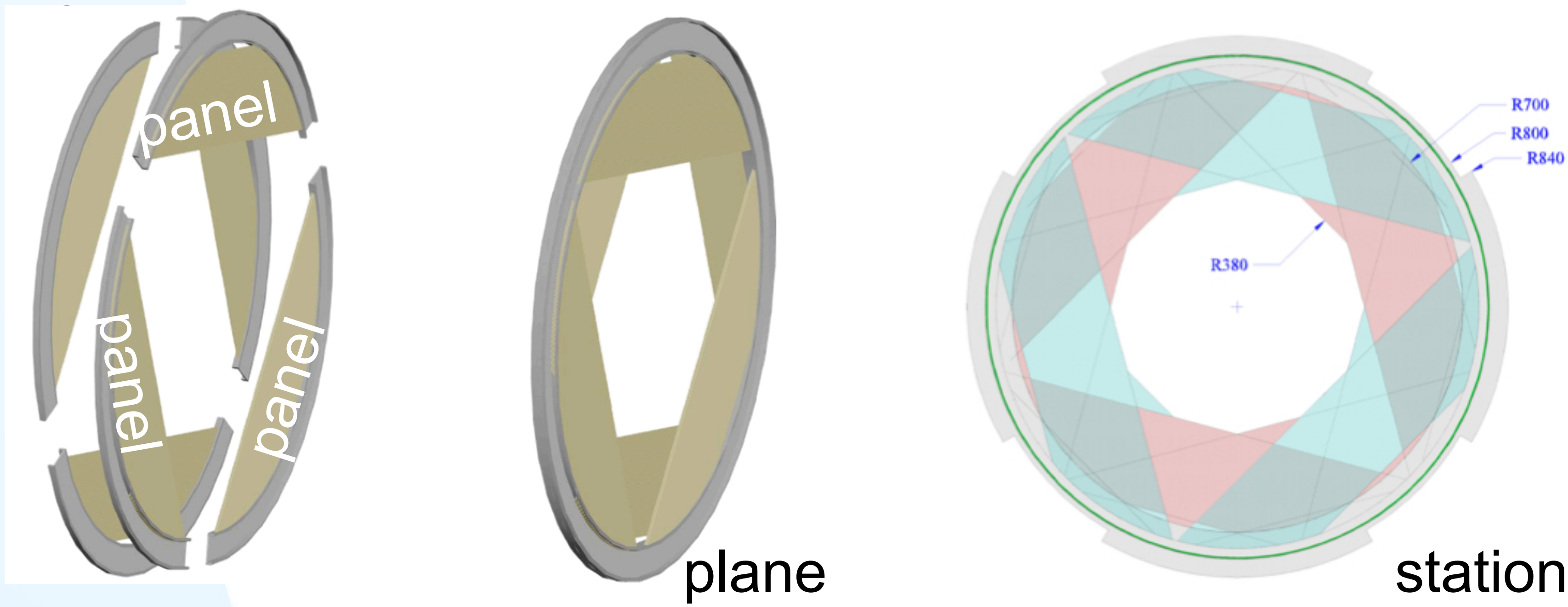
- Requires high efficiency CR-veto system, PID

The Mu2e Tracker

- Will employ straw technology
  - Low mass
  - Can reliably operate in vacuum
  - Robust against single-wire failures

- 5 mm diameter straw
- Spiral wound
- Walls: 12 μm Mylar + 3 μm epoxy
  + 200 Å Au + 500 Å Al
- 25 μm Au-plated W sense wire
- 33 – 117 cm in length
- 80/20 Ar/CO_2 with HV < 1500 V

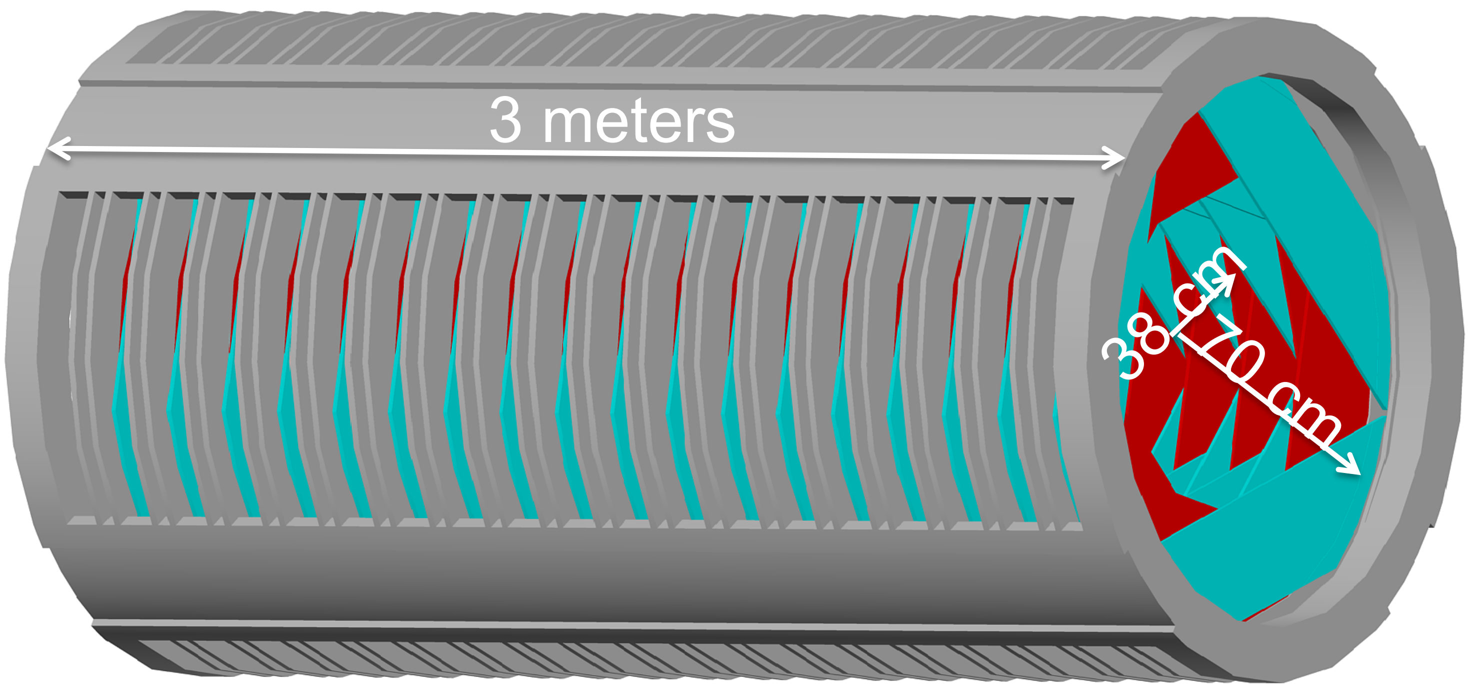
The Mu2e Tracker



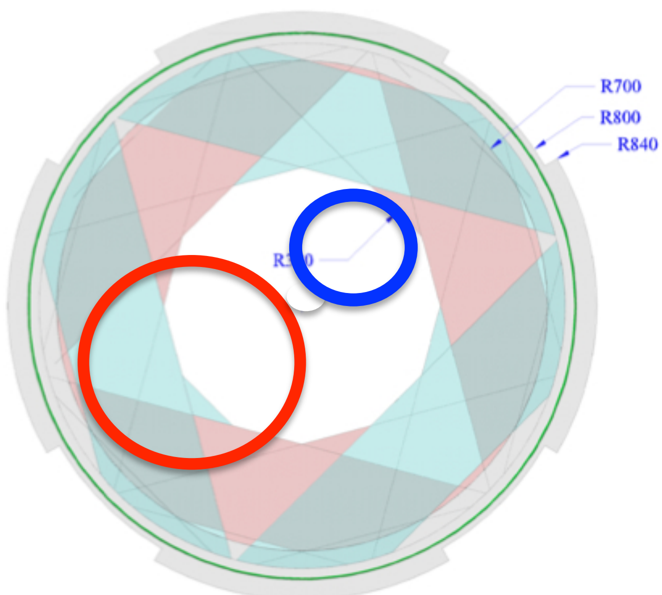
- Self-supporting "panel" consists of ~100 straws
- 6 panels assembled to make a "plane"
- 2 planes assembled to make a "station"
- Rotation of panels and planes improves stereo information
- ~25k straws total

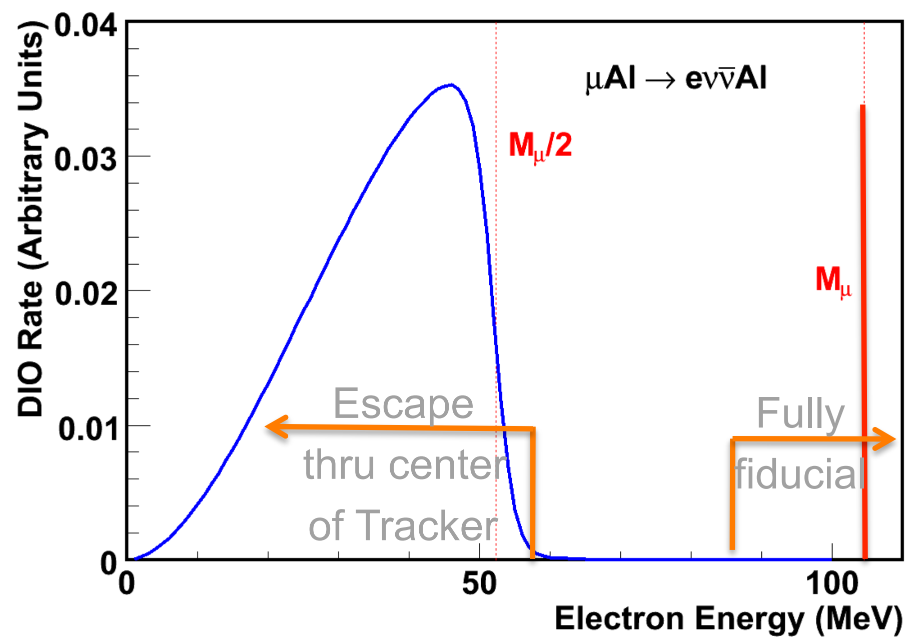
The Mu2e Tracker

- 18-22 “stations” with straws transverse to beam
- Naturally moves readout and support to large radii, out of active volume



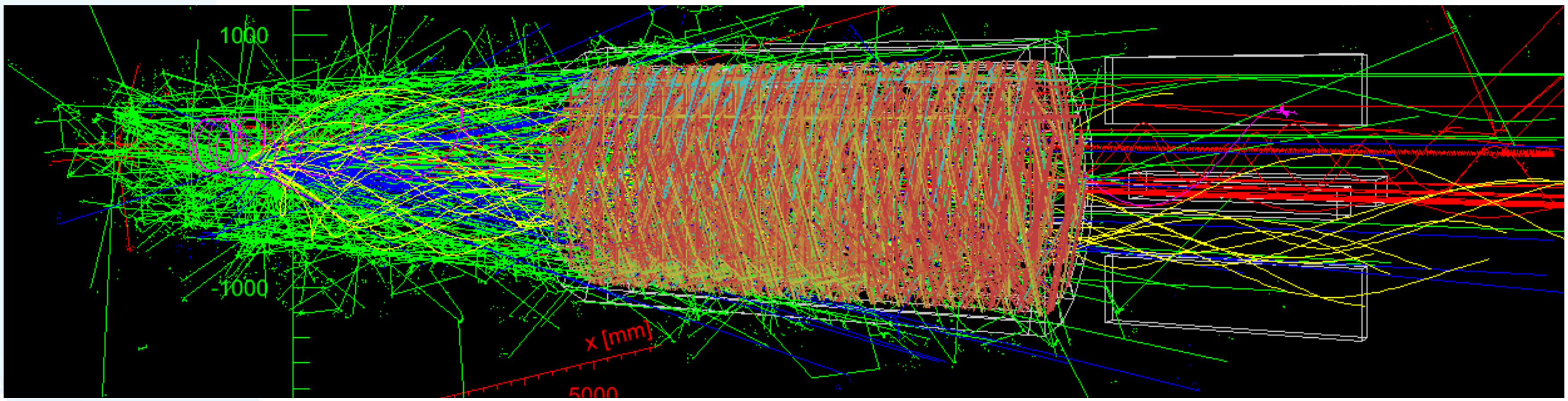
The Mu2e Tracker





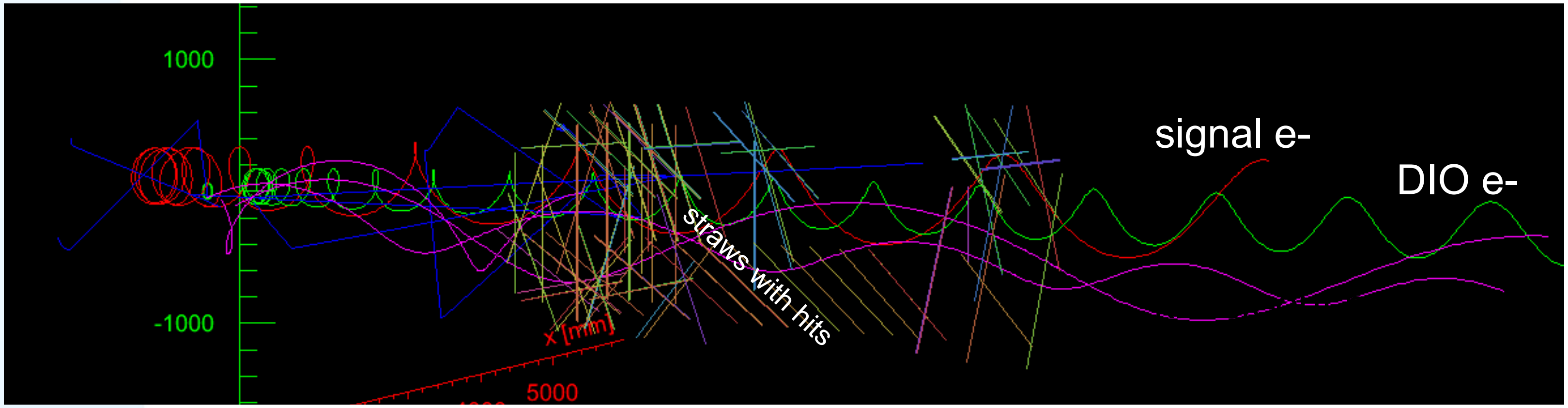
- Inner 38 cm is purposefully un-instrumented
  - Blind to beam flash
  - Blind to >99% of DIO spectrum

Mu2e Pattern Recognition



- A signal electron together with all the other “stuff” occurring simultaneously integrated over 500-1695 ns window

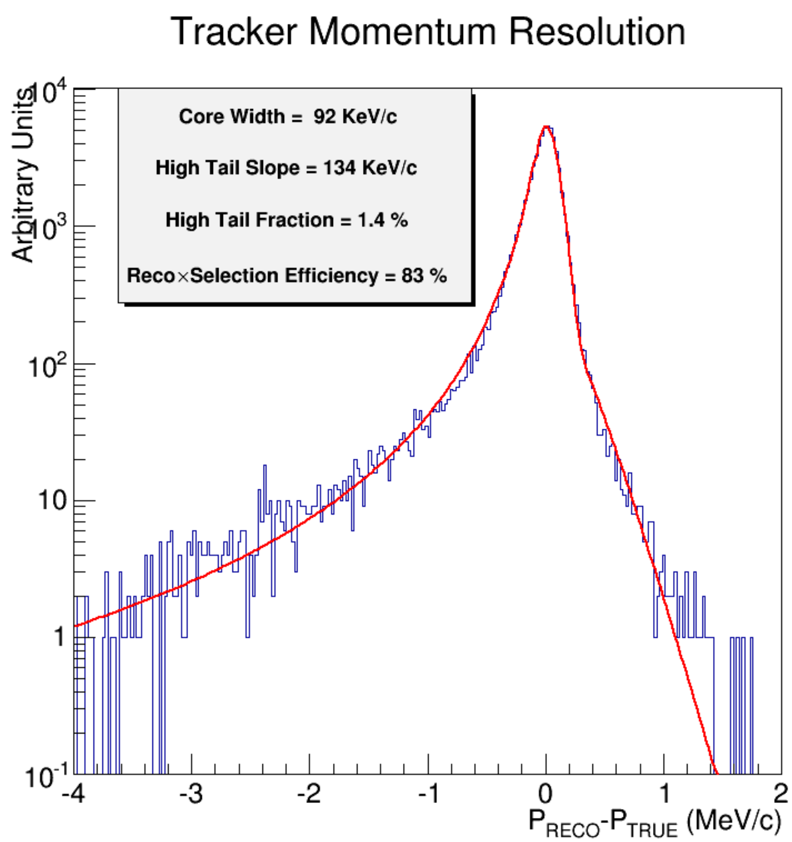
Mu2e Pattern Recognition



(particles with hits within +/-50 ns of signal electron t_{mean})

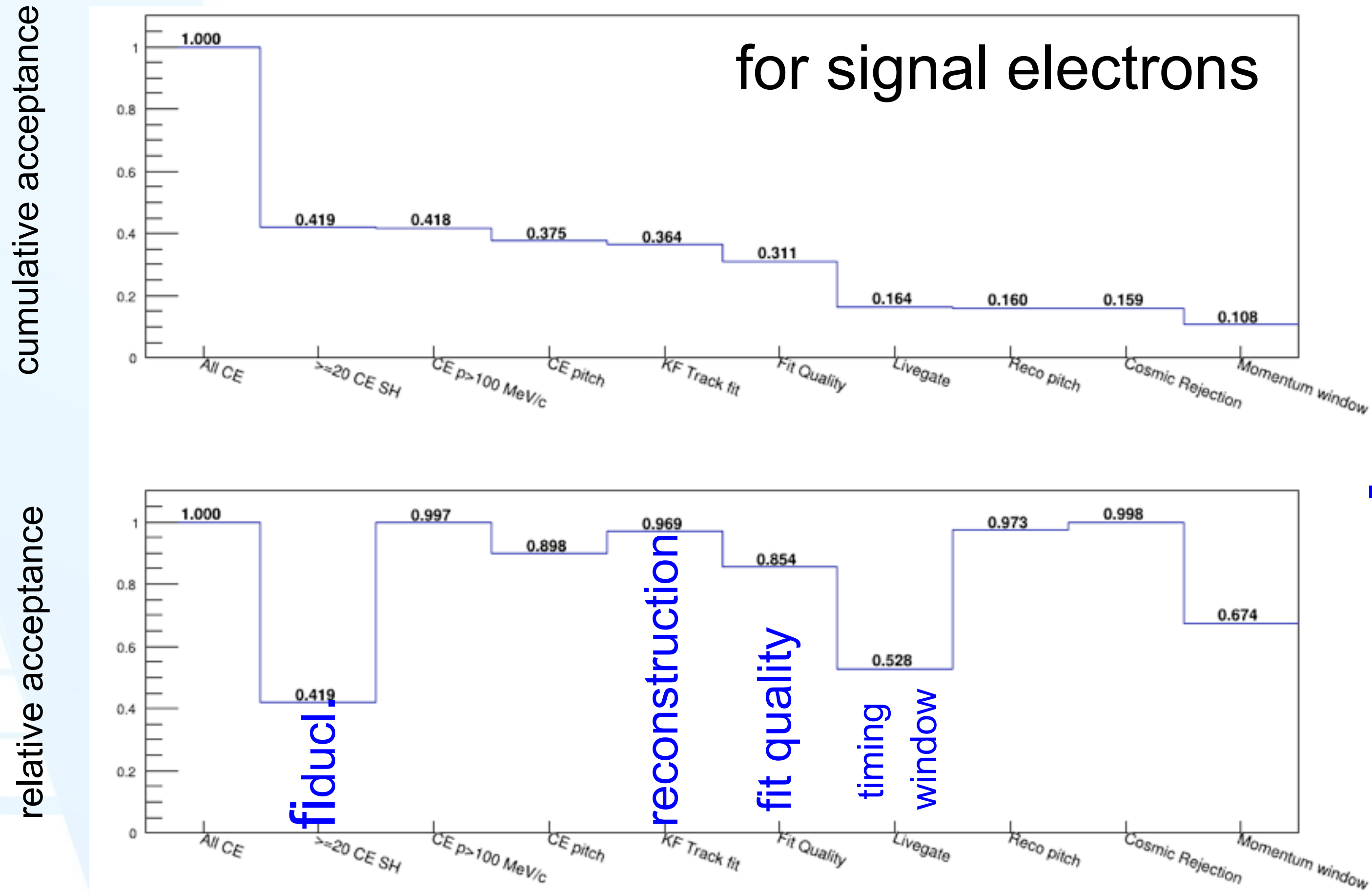
- We use timing information to look in +/- 50 ns windows – significant reduction in occupancy and significant simplification for Patt. Rec.

Mu2e Spectrometer Performance



- Performance well within physics requirements

Reconstruction and Selection Efficiencies



- Inefficiency dominated by geometric acceptance and delayed signal-timing window

Mu2e Calorimeter

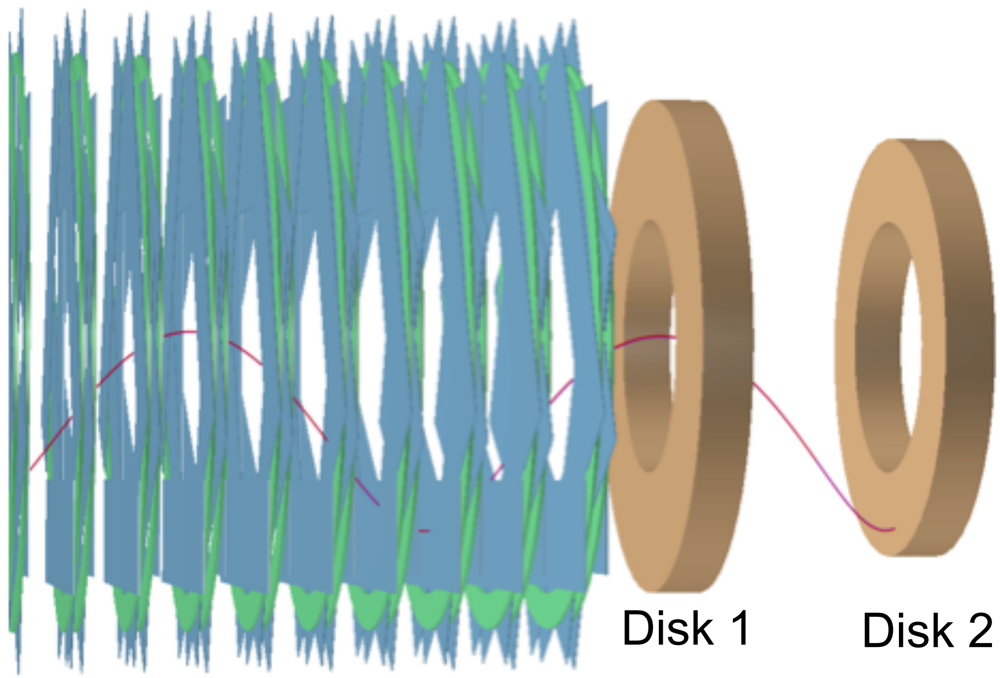
- Crystal calorimeter
  - Compact
  - Radiation hard
  - Good timing and energy resolution

Mu2e Calorimeter

- Baseline design : Barrium Flouride (BaF_2)
  - Radiation hard, very fast, non-hygroscopic

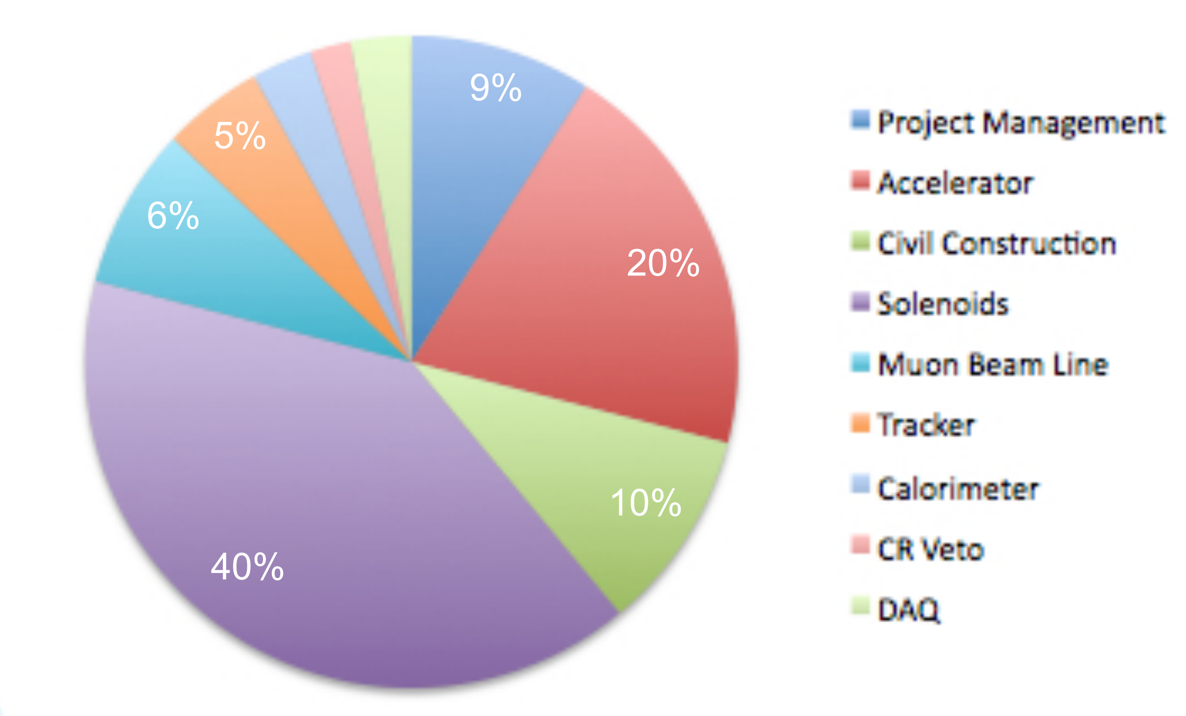
	BaF_2
Density (g/cm3)	4.89
Radiation length (cm)	2.03
Moliere Radius (cm)	3.10
Interaction length (cm)	30.7
dE/dX (MeV/cm)	6.52
Refractive index	1.50
Peak luminescence (nm)	220 (300)
Decay time (ns)	1 (650)
Light yield (rel. to NaI)	5% (42%)
Variation with temperature	0.1% (-1.29)% / deg-C

Mu2e Calorimeter



- Will employ 2 disks (radius = 36-70 cm)
- ~2000 crystals with hexagonal cross-section
  - 3 cm diameter, 20 cm long (~10 X_0)
- Two photo-sensors/crystal on back (APDs)

Mu2e Cost Breakdown



- Solenoid costs : Coils/Infrastructure ~ 65/35

Mu2e Sensitivity for TDR

- Background Working Group
  - Established March 2013
    (led by A. Gaponenko, FNAL WF)
  - Significant contributions from collaboration
    (D. Brown (LBNL), R. Ehrlich (U. Virginia), K. Knoepfel (FNAL), R. Kutchke (FNAL), Z. You (UC Irvine), V. Logoshenko (Boston))
- Staged approach
  - Factorizes work and facilitates detector optimizations and systematic studies
  - 2600M POT generated → 1M micro-pulses
  - 3 x 10^5 CPU-days, 10 TB of disk
- Studies ongoing, documentation in preparation